THERMO-ELECTRIC FLUID-METER AND HOT-WIRE ANEMOMETER

BY

WALTER M. SEYFERLICH

ARMOUR INSTITUTE OF TECHNOLOGY

1921

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A NEW THERMO-ELECTRIC FLUID-METER AND HOT-WIRE ANEMOMETER

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A THESIS

PRESENTED BY

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IN

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PREFACE.

In the Spring of 1920, Professor Freeman directed the author's attention to an article in the Journal of the Franklin Institute of 1916 by L. V. King on the "Linear Hot-Wire Anemometer and Its Applications in Technical Physics." For a thesis, it was suggested at that time, that some such subject would be of considerable interest and value,as an original investigation of this nature would naturally require considerable practical experimenting as well as analysis from the theoretical point of view.

After considerable study on the subject, the results obtained by the various authorities were thoroughly digested and it was deemed appropriate to undertake the development of a new type of hot-wire anemometer based upon a somewhat similar fundamental principle, but operating on an entirely new and original principle.

As originally suggested by Professor Freeman the investigation was to be based upon the use of an electrically heated wire, the temperature of which

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was subject to variations when subjected to relative motion with respect to air or gas, the magnitude of the variations being a measure of the velocity, and when calibrated properly the quantity passing any particular point. The distinguishing feature of the author's device is the use of thermoelectric indicating arrangements, which conveniently indicate or register any variations that occur at the surface of the heating filament of the anemometer. Many arrangements were then considered from a purely theoretical viewpoint and the most appropriate of these, or at any rate those which seemed to be most practical were chosen as the most desirable to work with.

Owing to the wide scope of the subject as compared with the very limited amount of time in which the thesis had to be completed, the entire subject was abandoned for the remainder of the year and the author left school. However, the theoretical investigation was carried on in spare time and although it would seem that many of the subjects discussed are superfluous, nevertheless the knowledge of all has contributed considerably toward the results already

obtained, and has likewise assisted the author in practical work outside.

In resuming the experimental work at the Institute early in March of 1921, the author was confronted chiefly by the problem of completing a suitable means of calibrating the instruments when once they were constructed. It should be noted in this connection, that it would be practically useless to make up such an arrangement as the hot-wire anemometer, without having some accurate and convenient means of calibrating the instruments. For this reason it may be stated that the greater part of the time was required in the construction of a suitable calibrating arm, so that the actual available time for the development of the anemometer itself was very limited. This, of course, prevented the actual completion or perfection of the Thermoelectric Fluid Meter, so that only enough results were obtained to show whether or not the theory upon which its operation was based is practically sound.

The results obtained are rather encouraging

and it is the hope of the author that expansion and further investigation upon the subject will serve as a thesis subject for an advanced degree.

Not only do the results show that the theory works out practically, but it is again demonstrated that the application of electricity to mechanical measurements is conveniently, as well as accurately, second to no other method.

As far as the commercial possibilities of the instrument are concerned it may be stated that the results would seem to indicate that such a meter will eventually serve for the measurement of velocities ranging from zero up to those values which may be accurately measured by means of the Pitot tube, and which have been given by the Bureau of Standards as 1800 feet per minute. This would be especially true in such installations as in the case of Warm Air Furnaces or Ventilating Systems where a permanent installation would be of advantage, and where the velocity is required at many points throughout the entire system.

A Thermoelectric Fluid-Meter, as we shall

see later, *might possibly serve as many instruments in one*, so that not only could velocity and quantity readings be recorded, but also the temperature, pressure, and quality of the particular gas as well, might be recorded at the point in question.

It is this latter feature as well as the flexibility and convenience of placing and reading electrical instruments in any system, that inspires one to continue such an investigation.

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INTRODUCTION.

During the last ten or twelve years many researches have been carried out and many experiments performed on the laws of cooling of electrically-heated wires either placed in a stream of air or gas in motion, or moved bodily and relatively to still air. Most of these investigations were carried on with the idea of applying this principle to the accurate measurement of air-velocity, and incidentally, researches of this kind were undertaken almost simultaneously by investigators in the United States, England, Italy, Germany, and Canada.

In this connection preliminary experiments on the use of a platinum wire heated by an electric current for the measurement of wind-velocity were carried out by G. A. Shakespear, at Birmingham, as early as 1902, but were discontinued for lack of facilities in the erection of a suitable whirling table or arm for calibrating the wires.

Probably the first real important work in Anemometry is that due to A. E. Kennelly at Harvard

in 1909, and although the results of his investigations were applied to anemometry as early as 1911, the complete details and information on the results were not disclosed until 1914. Electrical anemometry was also developed independently by U. Bordoni in Italy, 1911, and by J. T. Morris in Englans, 1912.

A series of researches and experiments were likewise carried out by L. V. King in Canada, 1912, and it was an account of these researches that practically suggested the development of the Thermo-electric Fluid-Meter described herein, but which needs considerable development work to be carried out.

A form of integrating hot-wire anemometer has also been described by H. Gerdien of Germany in 1913, while the use of a hot-wire anemometer in the measurement of non-turbulent air currents was described by C. Retschy of Germany, the year before.

Other researches were carried out by the following:

Russell in 1910.

Hughes in 1916.

King in 1912-13-14-15-16.

Bottomley in 1893.

Mitchell in 1900.

Hartmann in 1916.

Peczalski in 1916.

Considerable work due to Irving Langmuir may also be included although the results of his work were not applied particularly to anemometry or flow measurements.

Perhaps the most recent and important of these researches in anemometry are those of T. S. Taylor, 1919, who has devised the first hot-wire anemometer utilizing a thermocouple as a means of indicating the variations that take place at the surface of the heated wire. A complete description of Taylor's hot-wire anemometers are given in a later section. It is interesting to note that the work on the Thermoelectric Fluid-Meter was nearing the present stage before Taylor's results were discovered. The chief difficulties with his instrument are outlined in a later section and seemed to have caused the abandonment of his device altogether.

****

ANEMOMETRY.

HISTORY OF ANEMOMETERS.

The anemometer, or "wind-measurer" as derived from the Greek, is an instrument for indicating the velocity, and usually, direction of the wind. Ever since the birth of true experimental science, it has been recognized as a matter of great importance and interest to man, that he should know something of the laws according to which the atmospheric currents and changes are produced. Among meteorological phenomena, none deserve more attention than the elements of the wind; and none have received more. Yet anemometry has been all along the least successful department of meteorology, party owing, of course, to the nature of the agent to be dealt with, which is the very type of fluctuation, and party to a mistaken path of observation that was too long followed.

The error which, from the days of Hooke, in the middle of the 17th Century, to within a comparatively recent period, misdirected the efforts of inventors, was the idea that the elements to be

determined in the case of the wind are its direction and *pressure*, whereas practically they are its direction and *velocity*. If the currents of air were anything like uniform it would be a comparatively simple matter to deduce the velocity from the values of pressure; but their variability is so very great, that the relations between the velocity and the pressure become very complex. We know, from the elementary principles of dynamics that the pressure at any instant will vary as the square of the velocity. Obviously, therefore, the relative variations of the pressure will be twice as great as those of the velocity; and the latter, as we have found them, are already too great to encourage us to double them artificially. It must also be remembered that, from the inertia of the indicating apparatus, errors will in most every case arise; and these also will be doubled if we observe the values of pressure instead of velocity variations. From all this it will appear that comparatively little importance is to be attached to the earlier and to all statical modes of anemometry.

The essentials of every anemometer in

meteorological service are two: (1) a wind-vane to indicate changes in direction of the wind, and (2) a wind-gauge, or velocity-meter, to indicate changes either directly in velocity, or indirectly in force of the wind. There is also a distinction which we may have in every kind of meter. They may be either non-recording, as merely exhibiting the variations that take place to the eye; or recording, or marking the variations permenently on paper.

The wind-vane, or weather-cock as it sometimes is known, is simply a flat sheet of thin metal, or two sheets in the shape of a thin wedge, placed at the end of a metal rod, the whole arrangement being free to rotate on a vertical axis. Besides serving to indicate the direction of the wind itself, the vane is often used to turn the anemometer or gauge, so as to present the pressure-surface with its face always direct to the wind. In this manner only the component velocity values might be recorded, when all parts are arranged properly.

Of all the gauges that have been invented or proposed, it would be almost impossible to give

even the names. The primitive statical forms of anemometer - for example, setting against the force of the wind a gradually increasing resistance, with some means of indicating the point of balance - have been divided by Dr. Robinson into three classes, as follows:

(1) Vertical wind-mills, kept facing the wind by means of a vane, and acting by winding on their axle a string by means of a finely graduated resistance. Of this nature, were Dr. Hooke's anemometer, which is generally considered the first practical attempt in wind-measuring, and those of Wolfius and Martin.

(2) This class consists of those in which the wind acts on a flat plate, usually a foot square, pressing it against the elasticity of either a metallic spring or of a definite mass of confined air or gas, a previous graduation and calibration of the elastic force having been made for each instrument. The first gauge of this type was invented by the celebrated Bouguer, about the middle of the last century; and since his time there have been many attempts at improvement of this principle, the apparent simplicity

of the spring-measure being its recommendation. Modified forms of Bouguer's wind-pressure gauge are in use even at the present day; and about a half a century ago a self-registering adaptation of it was constructed by Osler, and very generally employed.

(3) The third class measures the wind-force by the difference of level it is capable of producing in an inverted syphon or U-tube, containing water or some other liquid. Lind's anemometer, invented in 1775, is the best known of this type and is still in common use. It consists simply of a U-tube, with one leg bent at right angles towards the upper end, and attached to a vane, so as to have its mouth constantly facing the wind. It is generally half-filled with water and a scale graduated to hundredths of an inch is attached. The difference of level in the liquid in the two legs of the syphon indicates the force of the wind; but it was only by experiment that the pressures corresponding to these differences could be laid down. Thus each instrument at that time required a carefully-constructed reference-table

of pressures and velocities corresponding to its readings. According to Lind, a difference of level of 1 inch indicated a pressure of 5.2 pounds per square foot, and that value corresponded to a velocity of about 32-1/2 miles per hour, which in those days was considered a high-wind. A difference of 3 inches in the leg-levels would indicate the approach of a storm, while one of 6 inches would indicate a hurricane.

(4) Rivalling the above type in simplicity is a fourth class, that may be added to Dr. Robinson's; this type is a pendulum anemometer, where the pressure-plate is swung as a pendulum, and indicates the wind-force by its deviation from the vertical. The first of this form was invented by the Marquis Poleni, and gained the prize of the French Academy in 1733. They are still employed as convenient indicators of the strength of the wind forces and are commonly called pressure-plate anemometers.

Many other anemometers have been contrived, which, owing to the period in which they were invented were regarded merely as interesting for the more

curious. Among these might be mentioned:

(5) A musical anemometer, suggested by Dr. Hooke, and constructed by Delamonon, in which the wind to be measured was caused to sound automatically, in a set of pipes, a particular note depending upon the dimensions of the pipe and velocity of the wind.

(6) Leslie's Anemometer, or rather, anemometric principle, which deduces the velocity of the wind from its effect in cooling a thermometer, it being supposed that the rate of cooling was proportional to the velocity of the wind.

(7) Brewster's evaporation anemometer, by which the velocity of the wind may be deduced from the amount of water evaporated in a given time from a given rough-open-surface, such as a sponge or flannel, the two being in proportion definitely known.

(8) Osler's anemometer or pressure-gauge-type of velocity recorder developed later and used very extensively in England was a more trustworthy and practical instrument than those mentioned above. It traced with a pencil on a sheet of paper which moved along either in a vertical or horizontal position, at

a constant rate by means of clock-driven mechanisms, lines which indicated changes of wind, both in direction and in pressure.

In this type of instrument, changes of direction were recorded by means of a vane mounted on an axle or shaft, with a pinion keyed on the lower end of the shaft. This pinion turned with the vane, and operated a horizontal rack, throwing it backwards and forwards as the vane turned one way or the other. The pencil or pen fixed to the rack traced its movements on the register sheet.

The changes of wind-pressure or wind-force, were measured by means of springs. A light metallic plate about one square foot in area, placed vertically and turning with the vane-rod, received the impulse of the wind, and was thus forced against three springs, so arranged that one, two or all three of them could be pressed on according to wind-strength. The extent of compression against the springs was transmitted through the hollow vane axle, by means of chains and pulleys, to a light spring which pressed a pencil gently against the paper.

Variations of motion of the upper plate thus corresponded to definite lateral deviations of this second spring pencil, and a wavy line was traced on the paper as it moved along. The register-sheet or chart was ruled across its length into twenty-four equal parts, one of which represents one hour interval, and hence passes the pencil points each hour. It was also ruled lengthwise with lines corresponding to the cardinal points, under the direction-pencil, and also on the field of the other pencil with lines spaced by actual experiment so as to correspond to graduations of 5, 10, 15, 20, etc. pounds of wind-pressure per square foot of surface. Thus the pressure-curve in the same way as on the indicator of a steam engine, included between it and the horizontal line of zero-pressure, a space proportional to the amount of work done by the wind on the upper pressure-plate. Of course, so long as the wind blew in one direction, the direction pencil traced horizontal lines, while if there were no wind at all, both pencils would trace the

zero horizontal lines.

Lack of time and space forbids us to enter particularly into the complete history of the direct velocity-measuring anemometers. It may be stated, however, that as long ago as 1783 one was contrived on this principle by Mr. Edgeworth for the measurement of air-currents, but to Dr. Whewell belongs the credit of first appreciating at its time value the velocity as opposed to the pressure measure. Owing, however, to some practical defects, such as the great frictional resistance of toothed wheels and endless screws, which at the time had greater effect on the indications of a gentle wind than of a high one, and to the want of an arrangement for indicating the **times** of the variations, Dr. Whewell's instrument quickly fell into disuse.

One of the most valuable contributions to this science was made by Dr. Robinson of Armagh, who between the years of 1843 and 1846, conducted a number of experiments and calculations on the proper form to be given to the revolving vanes. He found radical defects in the principle of all the vanes

previously employed; either their moving power was not sufficiently great to make the frictional correction inconsiderable, or their velocity, in place of being less, was often three or four times greater than that of wind, requiring greater complicacy of machinery to reduce the speed of the tracing point; or, lastly their results were not identical though constructed after the same type. The form adopted by Robinson to remedy these defects is that shown in figure Though it had been suggested to him by Edgeworth, it deservedly bears the name of the Robinson Cup Anemometer, as he was the first to show experimentally and analytically its advantege.

The arrangement consisted of four light metal hemispherical cups, of as large a diameter as practicable and convenient, extended at the ends of light and strong metal radii, so that they shall be as far from the axis of motion as possible so that the effect of friction become a minimum. They require no vane to keep them facing the wind as in other anemometers. Dr. Robinson found that the

cups move at almost exactly one-third of the rate of the wind velocity, when the dimensions are proportioned properly. This ratio was a very simple one and held for all instruments made after one pattern. Experiments were made with sets of two, three, four, and six cups; but the velocity ratio between the cups and the wind was simplest and most constant with four, the number which is now universally employed.

The complete theory and development of the Robinson Cup Anemometer, together with its advantages and disadvantages, are given in a later paragraph.

Anemometry, itself, has become a most important feature in all meteorological observations, and many important and remarkable results have appeared since the invention of self-recording and integrating apparatus.

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METERS FOR MEASURING GAS AND AIR.

The quantity of air or gas flowing in circuits or systems must be known in order to deal with the laws concerning flow: the knowledge is also required in working with practical problems which can occur, for example:

(a) In a compressed-air installation when it is required to know the air consumption of tools.

(b) In pneumatic-tube installations when it is desired to know the air consumption of each tube.

(c) In gas-engine work when one is investigating the question of obtaining the maximum efficiency, which depends upon the proportions of gas and air present; the same question arising with oil engines.

(d) In ventilation work, when the contractors and engineers require to know how much air is being circulated among the various rooms.

(e) In ordinary household gas supplies, where it is necessary to meter the gas used in each installation; similar metering should be done on the mains if practicable.

(f) In aerial navigation where a knowledge of the velocity of air currents is required. *In such cases it is the velocity at a **point** which is required*, and the velocity meters are preferred to the quantity meters.

In the first five cases, it is desirable to know the costs of working, of the overall efficiency of the plant being determined. If a certain quantity of air is required at a certain pressure, then the minimum quantity of work which must be done is the work required to compress or rarefy the specified quantity of air by means of isothermal compression or rarefaction to the specified absolute pressure; the actual work done will be much greater than this, on account of the losses in the machinery and in the various transformations of energy which are required in the various processes to produce the air at requisite place and pressure. The greater the overall efficiency, which is equal to the ration

$$\frac{\text{isothermal work necessary}}{\text{actual work done}}$$

the less will be the cost of working the plant, provided the maintenance charges are kept constant.

In all the above problems it is best to deal with the weight of air or gas, and not with the volume; and to reduce the weight to volume when the volume at a specified temperature and pressure is required. The weight of gas flowing is the only thing which is constant about the flow of gases in circuits as usually dealt with. The volume of flow is only approximately constant in any case, and is variable if the density changes much.

There are many different methods of measuring quantities, and different sorts of meters can be used according to what kind of flow is to be measured. The various methods may be roughly divided into the following nine types:

1. Measurement by Gas Holders.
2. Measurement in Containers or Receivers.
3. Displacement Meters.
4. Venturi Meters.
5. Orifice, Float, or Valve Meters.

6. Electrical Meters for Quantity Measurement.
7. Anemometers and other Meters.
8. Pitot Tubes.
9. Electrical Meters for Velocity Measurements, such as Hot-Wire Anemometers and Fluid-Meters.

The last three types of meters measure velocity directly, while all others are for quantity measurements.

One of the first questions which arises is the method of calibration. Assuming ideal conditions and perfect instruments, the measurement of gas in gas holders or in containers is absolutely correct; such methods form the usual standards in calibrating and recalibrating meters. Displacement meters form another ready means of calibration, but are more complicated in form, and are not convenient for ordinary investigators to have at hand. The Thomas electrical meter, the Venturi meter, and the Pitot tube usually require a small correction coefficient, the need for which prevents them being used as primary standards, but they are quite satisfactory for rough work without

being calibrated and without the actual value of the coefficient being known. Float and valve meters, ordinary commercial meters, and anemometers are quite useless unless the calibration is known.

Velocity meters can be approximately calibrated by passing them through still air at known velocities, which is the common method of calibrating Pitot tubes, for water and air.

Another method used by Threlfall was to inject smoke into a current of air and to watch the travel of the smoke and assume that it travelled at the same speed as the air.

In order to determine the velocity of air currents absolutely, Stanton used a specially constructed anemometer, which consisted of four very light vanes of aluminum placed at approximately 45° to the direction of air flow. The vanes could be rotated horizontally, and were suspended upon rollers which could travel up and down at an angle of 45° to the horizontal. An air current flowing vertically downwards tended to drive the

vanes and rollers down the plane on which the rollers rested; but if, at the same time, the vanes were rotated horizontally at the same speed as the air current, there was no force tending to move the vanes and rollers. The velocity of the air current was therefore given directly by the rate of rotation of the vanes. The force of the vanes due to gravity was counter-balanced by weights. The actual shape of the aluminum vanes was such that the intersections between cylinders coaxial with the direction of air flow and the vanes were helices at 45° to the horizontal.

Regarding the degree of accuracy, it may be said that if the readings and observations are made to less than 1 per cent accuracy, the humidity of the air must be considered; but such refinement is unnecessary for practically all commercial work.

The only definite quantity which remains constant when gas or fluid is flowing in a circuit and through a meter is the weight, and even this

will only remain constant as long as there are no leaks and no condensation on the walls of the circuit. In all gas meters, the pressures, velocities, specific volumes, or temperatures differ perhaps inappreciably, at the two sides of the meter, even if the area of the circuit remains constant, this difference being due to the loss of pressure in the meter; therefore, velocities or volumes as read by the meter can properly only apply to the circuit at one or other side of the meter.

Meters of the following types may be required: (a) Indicating; (b) Integrating and (c) Recording, which measure respectively:

(a) The instantaneous quantity, or velocity of air or gas; which will be given by orifice, Venturi, electrical meters or static anemometers.

(b) The total quantity of air or gas which passes in day or any other period of time, which will be given directly by gas-holders, displacement meter, and anemometer.

(c) The approximate quantity of flow at each moment over a long period, which will be given by any of

the above meters when associated with suitable recording devices, on the assumption that the pressure and temperature of the gas or air in the pipe at the meter is constant.

(d) The accurate quantity at each moment over a long period, which will be given by any of the above, when in addition to the recording devices there are also devices for compensating for variations in the pressure and temperature.

Wing describes methods of measuring large quantities of gas and discusses the direct methods of measurement, which include the diaphragm meters, gas holders, wet-drum meters, calibrated exhausters; and the indirect methods by use of inferential meters such as velocity meters, anemometers, shunt meters, and calorimeters. He mentions the Wylie shunt meter, where a portion of the gas is shunted through the meter. He quoted Weymouth's formulae for flow, but omits to state the units in which the quantities are measured; and states that the Pitot tube meters may be as much as from 10 to 20 per cent off.

There are many comparisons of flow as measured by different methods. He gives the comparative initial costs of different types of meters, for main stations, as:-

Wet Station Meters	100 per cent
Rotary or Blower Meters ..	50 " "
Thomas Electric Meters ...	38 " "
Proportional Meters	30 " "
Venturi Meters	12 " "
Pitot Tube Meters	1/2 " "

and figure 12 of his article shows the comparative costs of maintaining the wet meter and the Thomas electric meter, which is more economical when the flow to be measured exceeds 25,000 cubic feet per hour. If the above figures are true, one would naturally expect that the Venturi meter be used mostly, or at least more extensively, as it is on the whole quite accurate.

****

MEASUREMENT BY GAS-HOLDERS.

****

The most appropriate and accurate method known to the author, that would serve as an absolute method of calibration for such meters as the Thermo-electric Fluid-Meter, seems to be by means of Gas Holders. This is a perfectly accurate method if the mean temperature of the gas or air confined in the holder, is known, as well as the pressure existing therein and the absolute volume. There is no particular difficulty in knowing the values of these latter constants, and owing to the more recent developments in thermocouples and other devices for measuring the temperature accurately, there should be little difficulty in determining the mean temperature. This of course, has been the chief draw-back to this method, but will undoubtedly be overcome in the near future. The holder itself is usually relatively large and hence the temperature may vary from one side to another, or in fact, from one point to another, or from the bottom to the top. This, of course, would necessitate the obtaining of a good many temperature

readings at different points in order to determine the value of the true mean. The temperature may vary also in the time interval during which the readings are being taken so that for the most accurate results an instantaneous indicator would be desirable that would have little or no thermal lag and hence respond very quickly. The quantity of gas flowing into or out of such gas holders may be expressed as follows:

$$
\begin{aligned}
W &= V'd' - V''d'' \\
&= \frac{V'P'}{C\,T'} - \frac{V''P''}{C\,T''}
\end{aligned}
$$

where the suffix (') refers to values at the beginning of the test or experiment and the suffix (") refers to the quantities at the end, and

W = quantity flowing
V' and V'' = volumes of gas-holders
T' and T'' = temperatures in gas-holders
P' and P'' = pressures of gas in holders
C = gas constant
and d' and d'' represent gas densities.

Such a means of calibration would probably serve as an absolute standard for calibrating Pitot

Tubes, Thomas Meters, Venturi meters, Anemometers and many other types of meter. The temperature indications might be conveniently obtained by placing many small thermocouples at various points throughout the gas in the holder and connecting all of them by means of special switching devices to the same electrical indicator or measuring instrument such as a Pyrovolter. It is, therefore, suggested here that such equipment as Gas Holders and containers be given careful consideration for installation in the proposed laboratories of the New Armour Institute.

GAS CONTAINERS:

This is a common method for determining the output of air compressors and like the Gas Holder method, is likely to be exceedingly inaccurate if the temperatures are inaccurately known. The size of the containers is usually small, and there is no ready means usually available for inserting thermometers in the interior of the container, and since the variations which occur in the gas or air do not communicate themselves quickly to the outside of the plates forming the container, the only solution in view would be as given for Gas Holders, the use of small thermoelectric

temperature indicators placed throughout the gas.

This method is very satisfactory for use as a standard if one employes high pressures with accurate gauges, so that the range of pressure is great, and if one allows the temperature to attain the normal, or attain a fixed temperature when readings are taken. This can be done only if a relatively long time elapses after each time that air has flowed out of the container to the instruments under test, during which period of rest the air in the container can regain heat after it has been cooled by the expansion during test.

The equation for weight of gas in this method is

$$W = V'd' - V''d''$$

$$= \frac{V'}{C}\left(\frac{P'}{T'} - \frac{P''}{T''}\right)$$

as V' is constant here.

This method has been used extensively for calibrating orifice meters and orifices, in fact the Cutler-Hammer Company uses such arrangements in the making and calibrating of the Thomas Meter which has become so widely known.

****

COMMERCIAL GAS AND AIR METERS.

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The meters which are most available for the measurement of gas and air are as follows:

(a) The bellows type for low pressure chiefly.

(b) The Thomas Electric Meter for either high or low pressure.

(c) Venturi-tube for either high or low pressure.

(d) Pitot tube foe either high or low pressure.

(e) Wet types for low pressure.

(f) Rotary Meters.

(g) The Republic Flow Meter.

(a) The bellows type or "dry" meter has usually a pair of leather bellows operating two diaphragms, after the manner of a piston in a reciprocating engine. The valve operation is exactly like that of a two-cylinder double-acting engine with quartering cranks. The movement of the diaphragms measures off volumes of gas. The pressure and temperature of the gas must be kept reasonably constant, as the accuracy of the meter is affected by variations in either or both. The allowable error introduced may range from 3 per cent "slow" to 2 per

cent "fast."

The wet meter is now used chiefly for large gas-works service, and its operation is somewhat like that of a rotary engine. The average error is usually from 3 per cent"slow" to 2 per cent "fast." The obtainable accuracy with large wet meters is within .1 per cent.

The Thomas electric gas meter consists, as indicated in figure 7 , of an electric resistance heater coil placed in the gas main, a wattmeter, and two screen-resistance thermometers. A definite amount of current is passed through the heater such that the difference of temperature of the gas before and after passing the heater is a definite amount as measured by the screen thermometers, which automatically average the temperature.

The relation between the temperature, watts input, and flow is then computed from the expression

$$W = \frac{.05686\ E}{s_p} \text{ lbs. gas per min.}$$

where t = temperature difference in degrees Fahrenheit at inlet and outlet;

s_p = specific heat of air or gas at constant

THE THOMAS ELECTRIC METER.

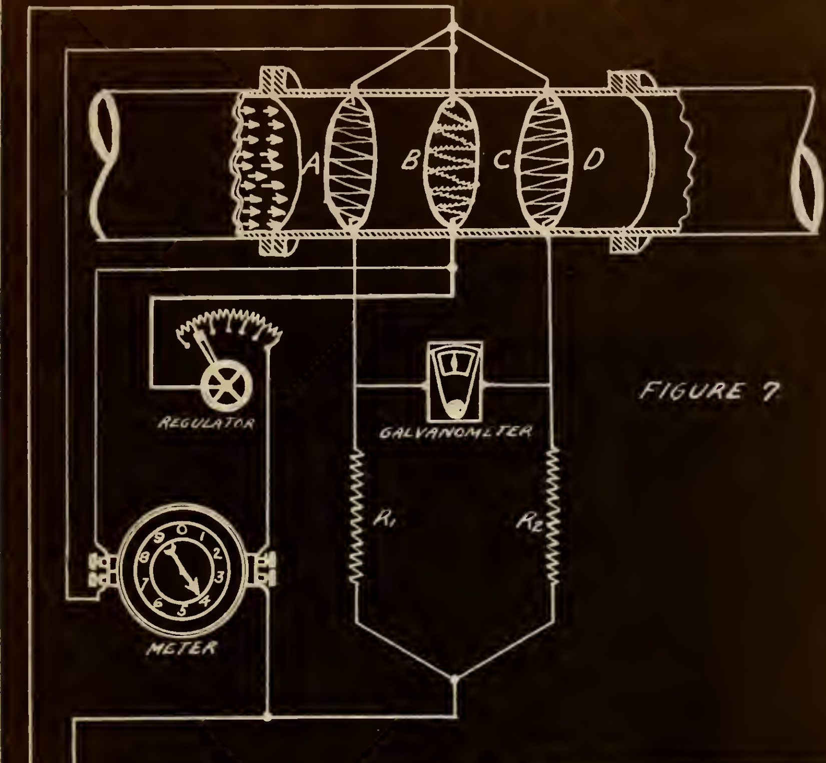


FIGURE 7

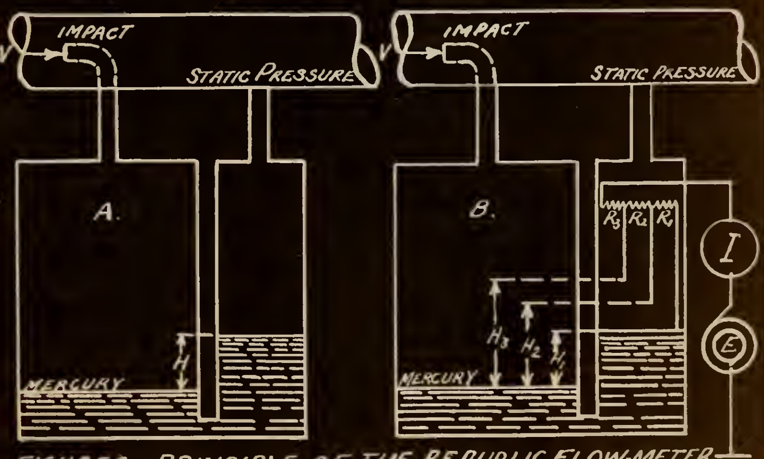


FIGURE 8.—PRINCIPLE OF THE REPUBLIC FLOW-METER

pressure;

E = watts input to heater.

The Thomas Meter is used as a substitute for the huge wet meters formerly employed at gas houses for the main-flow measurements. Its accuracy is higher than that of any other device now in use for air or gas flow, the error being from 1.05 to 1.2 per cent. In small sizes it is too expensive to compete with most other meters, but in large sizes it is much less expensive in proportion, and has the additional advantages of indicating and recording as well as integrating. In commercial service it is generally equipped with an automatic regulator, as explained below, arranged to keep a constant temperature difference between inlet and outlet. The electrical instruments may thus be graduated directly in pounds or cubic feet, as the quantity flow is directly proportional to the watts input.

One great advantage in this type of meter is the fact that the specific heat of air or gas is practically independent of small variations of the pressure or temperature and for commercial work is quite

independent of such variations as may take place. At any rate the variations in the specific heat from day to day due to the quality of the gas will be greater than those due to variations in temperatures and pressures during the day.

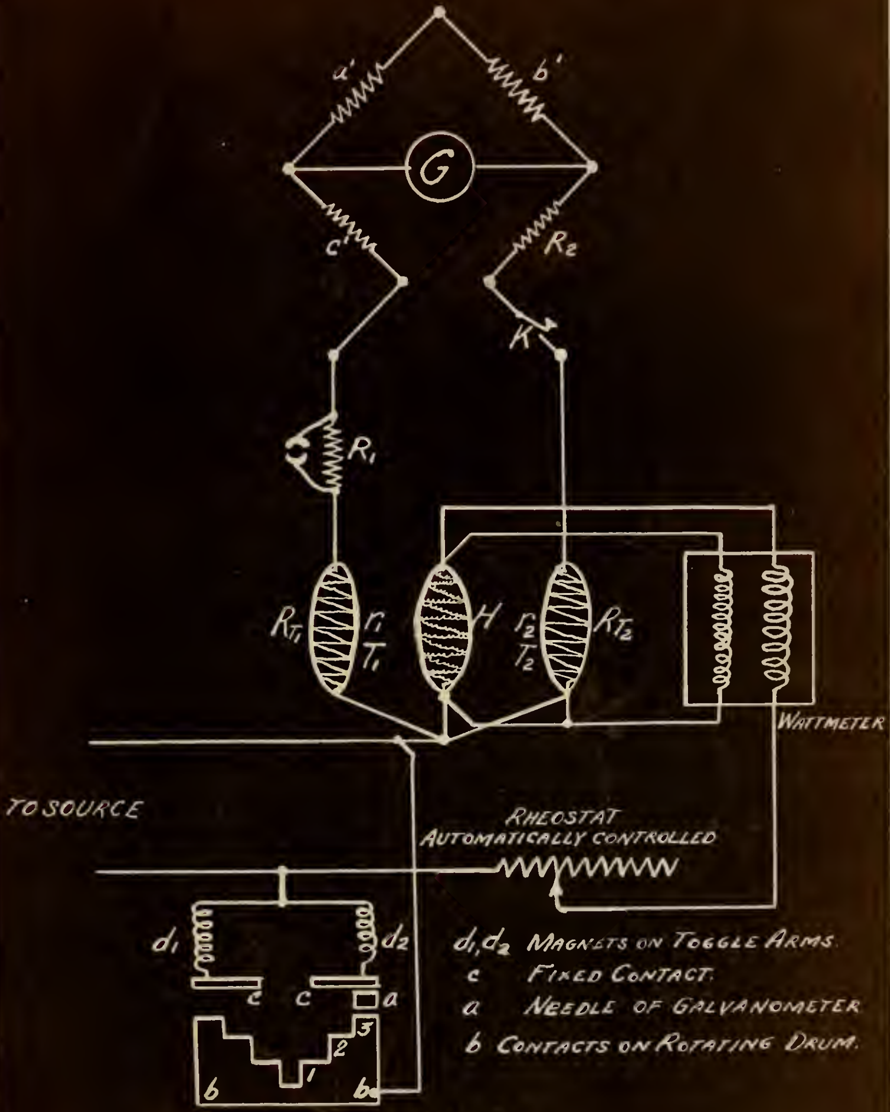
The heater is placed in some convenient spot in the pipe line in a special housing of its own in order to avoid losses by radiation. The two electrical resistance thermometers are introduced one on each side of the heat and form the two arms of a Wheatstone bridge. When the resistance of the second resistance unit rises as the temperature rises the bridge will become unbalanced and the galvanometer needle will be delfected. It could be arranged that this deflection would measure the quantity flowing in the pipe.

Thomas, in his experiments, compared quantities registered by his meter against quantities register by means of Pitot tubes and Venturi meters and found very close agreement. In the commercial form of Thomas meter, the galvanometer deflections are used to control the amount of energy imparted to the heater, so that the energy is varied as the quantity varies, the temperature difference between the resistance being kept as near constant as possible. This is done instead

of maintaining the power supplied the heater constant and allowing the temperature difference to vary with the varying quantities.

Figure 9 shows the meter in diagrammatic form, showing all electrical connections, etc. The heater which is a grid of resistance wire, is placed between two nickel resistance thermometers, as shown in figure 7. The resistance thermometer coils are kept at temperatures T_1 and T_2, such that T_2-T_1 is fairly constant and about one or two degrees Centigrade, the latter being the most generally used. A resistance R_1 may then be inserted as indicated, in order to compensate for the increased resistance of r_2 when heated, and has a value such that, when T_2-T_1 is the correct amount, say 2° C., the needle of the galvanometer will be in its central position. Now suppose that there is equilibrium and the energy imparted to the gas is just sufficient to heat it from T_1 to T_2, but that then the quantity of gas or air flowing is suddenly reduced. With the same energy imparted to the heater, the temperature T_2 will rise in value, and the galvanometer needle will be deflected.

ELECTRICAL CONNECTIONS FOR THE THOMAS METER.



d_1, d_2 MAGNETS ON TOGGLE ARMS.

c FIXED CONTACT.

a NEEDLE OF GALVANOMETER.

b CONTACTS ON ROTATING DRUM.

FIGURE 9.

An 1/8th Horse Power motor is running continuously, and also moves toggle arms provided with magnets, over the rheostat in the main energy circuit. If the galvanometer needle is displaced, the rotating drum makes contact with a and c, and the magnets on the toggle arms are energized. The magnets drop pawls into the teeth of the rheostat controller, and the toggle arms move the rheostat arms so that more resistance is introduced into the main circuit and less energy is imparted to it. Then the rise of temperature of the reduced quantity of gas becomes less, so that the galvanometer needle goes back towards zero. The amount of resistance added depends upon the number of contacts moved over by the rheostat arm; this depends upon when the magnets d_1 and d_2 are energized, which depends upon the position of the needle a. If T_2-T_1 is much in excess of the proper amount, a makes contact with b_3 and three additional units of resistance are cut in. If, however, T_2-T_1 is only slightly in excess of the proper amount, then a makes contact with b_1 and only one additional unit of resistance is inserted. The wattmeter in the circuit will then

register the integral of the quantity of gas flowing, when properly calibrated.

The galvanometer needle is clamped for a short time during each revolution of the contact drum, while contact is being made.

Two sorts of equations are desirable, one giving the units required to heat a given quantity of gas or air, and the other giving the quantity of flow which can be metered by any input, so that one can see at a glance what cost is required for the meter, and what particular voltage and current would be required to meter a certain flow per second. For this it is necessary to know the specific heat of a gas at constant pressure s_p, which generally lies in commercial work, between .2068 and .2182, with usual values of .209 to .211 .

The derivation of the working equation is as follows:

Let s_p = the specific heat = .2375 for air
or = .211 for gas

s_p calories of heat being the amount required to raise 1 kg. of fluid 1° Centigrade, or 1.8° Fahrenheit.

1 calorie = 4190 watts

1 B. T. V = 1055 watts

and let the temperature rise T be 1° C. or 1.8° F. The watts generated

E = (constant) (quantity of air) (Temperature rise) in metric units

$$\frac{E}{4190} \times \frac{1}{s_p} \times \frac{1}{T} = \text{kg. heated} = M\,t$$ where t refers to time.

Introducing kilowatt hours where 1 K. W. - H_r = 3600000 watts-sec.

$$M\,t = \frac{3600000}{4190\ s_pT} = 4070 \text{ kg. gas}$$
$$\text{or} = 3620 \text{ kg. air}$$

In English units

$$\frac{W}{1055} \times \frac{1}{s_p} \times \frac{1}{T} = M\,t = \frac{3600000}{1055\ s_pT}$$
$$= 9000 \text{ lbs. gas}$$
$$= 8000 \text{ lbs. air}$$

The following table (Table No. 0) shows the electrical energy required to heat various quantities and indicates that the cost of energy used in the heater is therefore not a serious item in the cost of upkeep, as it amounts to only 4½ d. per million cubic feet, if the cost of current is 1 d. per unit.

****

TABLE NO. 0.

Eng. Units.	Metric Units.
1 Kw-hr heats--	1 Kw hr heats --
i. 8000 lb. of air.	3620 kg of air.
ii. 105,000 cu. ft. free air.	2970 cu. metres free air.
iii. Flow at the rate 2·2 lb/sec.	Flow at rate 1 kg/sec.
iv. 9000 lb. of gas.	4070 kg of gas.
v. 236,000 cu.ft. of gas at p_0.	6680 cu. metres of gas at p_0.
vi. Flow at the rate of 2·5 lb/sec.	Flow at rate 1·13 kg/sec.
If the flow is: - M lb./sec.	M kg/sec.
Watts required = 0·455 M, air. = 0·400 M, gas.	Watts = 1·00 M, air. = 0·885 M, gas.

ELECTRICAL ENERGY REQUIRED TO HEAT VARIOUS QUANTITIES.

ANEMOMETERS.

Perhaps the most common form of meter in general use for measuring the flow of air at atmospheric pressure, as in ventilation work, is the anemometer, which registers the velocity of air currents. One form of this well known instrument consists of vanes placed at an angle of about 45° to the axis of flow, and which is directly connected or geared to an indicating pointer which registers on a dial the number of revolutions made by the vanes. This form of anemometer, (and practically all others that work on the principle of a revolving set of vanes or cups) records the total flow in any length of time, and, therefore, if the velocity per second be required it becomes necessary to record the readings with reference to a timing mechanism such as a stop-watch.

Before one can determine quantities, the readings of pressure, temperature, and the area of the pipe, as well as the calibration of the anemometer itself must be known. But, apart from this, the anemometer is a very useful instrument for

measuring velocities of winds, and air currents where the area across which the air is blowing is free space, and therefore indefinitely greater than the area of the anemometer. For ventilation work, where the air is flowing in ducts of say 3 feet in diameter, small anemometers are also suitable, as the introduction of the meter will have no appreciable effect upon the current of air in the duct. This is not so when the area of the meter is large in comparison to the area of the pipe, or when all the air entering circuit must flow through the meter. In the latter cases the meter must be calibrated in position if the readings are to be accurate. When the velocity of air in open spaces is being metered, the conditions are those which usually exist under calibration.

The usual method of calibration consists in rotating the anemometer at a definite speed in still air, and noting the revolutions of the dial hand and the speed of rotation. The only inaccuracies which arise will be due to the existence of local currents set up by centrifugal force.

Calibration by moving the meter in a straight line would be preferable, but is difficult to obtain on account of the legnth of travel that would be necessary, and the difficulty of obtaining sufficient velocity.

In this connection, Hackett describes a method of calibrating anemometers by means of secondary standard as used by him in Siemens' Works, Stafford. Ordinary anemometers which read velocities up to 60 feet per second, or 20 meters per second, are accurate when used by careful observers, but require re-calibrating regularly, and it is troublesome to send them away to the makers laboratory for calibration each time. Hackett therefore used a fan coupled to a variable-speed motor as the secondary standard; the quantity of air delivered by a fan is approximately proportional to its speed. This law he verified for the particular fan used up to 120 meters per second as the peripheral speed, and to outlet velocities up to 27 meters per second, using a pitot tube as the primary standard.

Rietschel states that the calibration of

anemometers by whirling may differ by as much as 13 per cent from the calibration by volumetric methods, which are more preferable. For measuring large quantities of flow in large pipes by means of anemometers, Rietschel used a bank of 14 anemometers placed in various positions across a pipe, and found that an accurate result of the quantity flowing could then be obtained; but to use such a quantity of meters in one pipe is not ordinarily practicable. The above mentioned tests were carried out at the experimenting rooms of the Königliche Technische Hockschule, Berlin, where specially elaborate arrangements have been made for such work. Gas-holders and wet Biabbée meters are employed as the primary standards. A full account is given in reference (b).

When a meter is set up in a pipe line, the existing distribution of velocity is upset, and the velocity of air through the meter will be greater than the velocity previously existing in the space taken up by the meter, owing to the reduced total effective area of pipe. The meter will tend to

register velocity u', which will exist over the area S', instead of registering the velocity U, which exists over the area S. The amount of reduction in area due to the meter cannot be determined by theory, and either this must be allowed for arbitrarily or the meter calibrated in position.

If, however, the meter is small relative to the pipe area, the readings will be accurate enough, and then the only correction required will be for the ratio of the velocity where the meter is placed, to the mean velocity in the pipe; the velocity distribution must be taken as "known," or experimentally found. The ordinary anemometer of rotating type is convenient in being an integrating meter, but its great disadvantage is its inaccuracy. A restraining force exists in the friction of the pivot of the vanes and of the wheel of the registering dial; this force is not constant, but depends upon the state of the instrument; and if the flow varies from moment to moment, the vanes will not be able to respond to such variations owing to their

moment of inertia.

Then the meter is of no use apart from its calibration: the scale registers correctly only at one particular velocity; the magnitude of the inaccuracies varies immensely; some writers put it as high as from 10 to 20 per cent.

Barclay and Smith describe the use of anemometers in measuring the volumes of cooling air used for turbo-alternators. They were satisfied that the anemometers were as accurate as the Venturi meters, and that readings could be taken more conveniently than with the Pitot tubes, because there was no liquid pressure gauge to be manipulated. In the discussion upon the paper some authorities cast doubt upon the accuracy of the anemometer.

Beardsmore describes an anemometer which can be placed in a gas main to register the total flow of gas and also to measure the fluctuations of flow. An ordinary anemometer is used, and no mention is made of the correction factor which would be necessary on account of the velocity distribution not being uniform, which would therefore require the

calibration of the meter in position.

Robinson has dealt with the question of the forces on cup anemometers due to winds, but as such types of anemometers are not ordinarily used in measuring the flow of air in channels, no extracts from his work are given here.

REFERENCE B:

(Mitteilungen Prüfungs Heiz. Anstalt, p. 40).

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DEFLECTING OR INDICATING ANEMOMETERS.

So far only the ordinary type of anemometer with revolving vanes has been under discussion, but there is another type, in which the revolution of the vanes is prevented by a spring or some other type of control, or where some

other form of surface can be deflected against some controlling force. These forms of anemometers are indicating meters, as opposed to the integrating meters, and their indications show pressure due to air currents, so that the pressure values may be interpreted in velocities, once the meter has been calibrated.

This calibration will partly depend upon the laws concerning the pressure of moving air on plane surfaces, or on curved surfaces. Such an indicating meter can be made extremely sensitive, if very light vanes are pivoted very freely; shaw used mica flaps in experiments in some of the lecture rooms at Cambridge University, and was able to detect convection currents due to the warmth of a person's hand by this means.

Stanton describes experiments made upon the air pressure on discs placed at right angles to a flow of air. It was found that the form of distribution of air velocity across a pipe or tube was greatly altered if a disc of appreciable size in comparison to the area of the pipe were introduced in the pipe. The effect

became noticeable in a 2 foot pipe when a disc of more than 2 inches in diameter was introduced, i. e., when the area was diminished by .7 per cent.

In measuring the pressure on discs, it must be remembered that the pressure read in the ordinary way is a resultant pressure due to the positive pressure on the front of the disc and a negative pressure, or suction, acting on the back of the disc. The amount of this resultant pressure is given by various authorities, as noted in the table on the following page.

(See table on following page)

Stanton found that the shielding effect of two planes placed one behind the other, is greatest when the distance apart of the planes is

TABLE NO. 1.

Pressures given in	Lb./ Ft.^{2}		: Kg./ Meter^2	
Velocity being given in	Miles/Hr.	Ft./Sec.	Km./Hr.	Meters/Sec.
Conversion factors	K = A	K= .465 A	K= 1.9 A	K = 24.4 A
Stanton	2.7	1.26	5.12	65.8
" Froude (carriage)	3.66	----	6.95	89.3
" Dines (whirling table)	2.80	----	5.50	70.6
" Langley (" ")	3.26	----	6.20	79.5
" Langley	3.90	----	7.40	95.0
Shaw quoting Dines p. 91	3.00	1.4	5.70	73.2
" Stephenson	5.00	2.32	9.50	122.0
Kempe	(2.86	1.33	5.43	69.6
	(3.27			
Krell	3.5	1.52	6.20	80.0
Grashof	5.00	1.63	6.70	85.5
Stanton plate 25 ft.^{2}	3.2	2.32	9.50	122.0
" " 50 "	3.18	----		
" " 100 "	3.22	----		
Thurston, round wires	(2.55	----		
	(2.80	----		

Pressure = $K u^2$

Table giving values of 1000 K - which gives pressures in lb./ft.^{2} Kg./meter^2, when velocity is given in miles/hour ft./sec., Km./hr. and meters/sec.

1.5 times the smallest width if the planes are rectangular, or 1.5 times the diameter if the planes are circular. The effect of such shielding he has investigated fully in connection with the determination of wind pressure on braced structures, girders, etc.

Buchholz describes Bornstem's wind meter, which consists of a ball fixed on the end of a pivoted rod, whose lower extremity carries a pencil which registered graphically the wind pressure.

The indicating vane type of meter could be utilized as an indicating meter in a pipe line, if calibrated in position, and if the position of the flap or vane was visible from the outside, through a glass window. If the motion of the flap was transmitted to the outside of the pipe through a bearing and a rod or extended axis, the friction of the rod in its bearing would make the readings quite unreliable. But a freely pivoted vane should give very accurate readings, as the pivot friction can be made negligible.

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THE PITOT TUBE AND OTHER ANEMOMETERS WITH REFERENCE TO AEROPLANES.

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INTRODUCTION:

The air pressures on the wings of an aeroplane, and therefore the sustaining power of the wings and the stresses to which the whole structure is subject, depend on the speed of the machine relative to the air through which it is moving. The measurement of this speed - particularly near the lower limit where the sustaining power becomes deficient and there is danger of stalling, or at very high speeds where any movement of the controls may give rise to dangerously large stresses - is evidently a matter of importance, and the use of a reliable anemometer or speedometer is highly desirable. The aim of the following section is to describe the principles of operation of some of the instruments which have been devised or used for this purpose and to discuss their characteristics, so far as it can be done from a general point of view or on the basis of available information, without undertaking new

experimental investigations.

Since the Pitot tube is the instrument which has been most commonly used in the United States and Great Britain as a speedometer for aeroplanes, it will be treated first and somewhat more fully than the others.

THE PITOT TUBE:

The speed-measuring device known, after its inventor, as the Pitot tube contains two essential elements. The first is the dynamic opening, or mouth of the impact tube, which points directly against the current of liquid or gas of which the speed is to be measured, and receives the impact of the current. The second is the static opening for obtaining the so-called static pressure of the moving fluid, i. e., the pressure which would be indicated by a pressure gauge moving with the current and not subject to impact. To avoid the influence of impact, the static opening points at right angles to the dynamic opening. If the two openings are connected to the two sides of a differential pressure gauge, the

gauge shows a head which depends on the speed and density of the current in which the tube is placed, and which may be used as a measure of the speed of the fluid past the Pitot tube.

If the fluid is a liquid and the two openings are connected to a U gauge containing the same liquid, the gauge shows a head h and the usual formula for computing the speed S is

$$S = C\sqrt{2gh} \qquad (1)$$

in which g is the acceleration of gravity and C is the "coefficient" or "constant" of the given instrument. If the head h is read on a gauge containing a liquid of density d while the density of the fluid (either gas or liquid) in which the Pitot tube is immersed is p, equation (1) takes the modified form:

$$S = C\sqrt{2g\frac{d}{p}h} \qquad (2)$$

According to the elementary theory as usually given, C should be exactly 1, and in practice it is in fact in the neighborhood of unity, when the instrument is properly designed and used with suitable pre-

cautions.

As regards design, it may be said that numerous recent investigations have shown that almost any sort of dynamic opening is satisfactory, but that the static opening must be designed with great care in order that the coefficient C may be set equal to unity without involving any sensible error in the result of using equation (2). Rowse, for example, has made an extensive comparison of various forms of Pitot tube, which confirms previous results obtained by White, Taylor, Treat, and others. With the most satisfactory tube tested, the experimental error in S was found to be not over 0.2 per cent. whether the static pressure was taken from a piezometer ring or from the static opening of the tube as supplied by the maker. The standard of comparison was a Thomas electric meter, which was assumed to give correct readings.

It may therefore be concluded that by proper construction the Pitot tube can be made to have a coefficient so near unity that for all ordinary purposes the equation

$$S = \sqrt{2g\frac{d}{p}h} \qquad (3)$$

may be regarded as sensibly accurate.

ERRORS WHICH MAY OCCUR IN THE INTERPRETATION OF PITOT-TUBE READINGS:

The simple theory which leads to equation (3) assumes that the tube is always pointed exactly against the current and that the observed head, h, is due to the instantaneous value of the speed S. These assumptions are never exactly fulfilled in ordinary practice and accordingly exact results may not be obtained, even when no fault is to be found with the instrument itself.

In the first place, it is impossible to read the gauge instantaneously; furthermore, there is always a time lag betwean the openings and the gauge. Accordingly, even when the current does not change in direction, if its speed varies rapidly all that can be observed is the mean value of h over a certain time interval, and this value does not correspond to the arithmetical mean value of S over the same interval, even if the interval is long compared with the time lag, as has been shown experimentally by Rateau.

Disregarding the time lag, the value of S computed by equation (3) will be the root-mean-square speed, which is always larger than the arithmetical mean speed. Hence if, for example, the Pitot tube is being used to determine the discharge through a steam main feeding a reciprocating engine, the computed discharge will be greater than the true discharge. This error is not likely to be very large. If, for instance, the speed varies sinusoidally with time from 0.5 to 1.5 times its arithmetical mean value, the linear speed computed by equation (3) will be 1.0607 times the arithmetical mean speed which determines the total flow, or a trifle over 6 per cent. too large.

A second cause of error is rapid variability in direction of the current, which makes it impossible to keep the tube pointed correctly even when mounted on a vane. If, as is usually the case, it is desired to measure merely the component velocity in a fixed direction, the eddies which almost always exist may introduce a considerable error when this component velocity is computed by equation (3). If the

variations of direction are small, the error is due almost entirely to the effect on the static opening and not to change of the direction of impact on the dynamic opening.

This source of error is much reduced in the Dines tube, a form of Pitot tube in which the static opening consists of a number of round holes or longitudinal slits in a hollow cylinder placed with its axis perpendicular to the direction of the impact tube and to the plane in which the variations of direction are expected to occur. When this instrument is employed as an anemometer, its principal use, the cylinder is of course vertical.

The heads given by the Dines tube are sensibly independent of errors in direction up to about 20° on each side of the mean. To offset this advantage, the instrument is somewhat less sensitive than the ordinary Pitot tube, the coefficient C being greater than 1. Furtherfore, each tube must be calibrated separately, and it is not even certain that the coefficient is strictly constant for each tube. Data by Dines show a constant coefficient

C = 1.53. Jones and Booth find values from 1.20 to 1.70 for different tubes. Zahm finds values from 1.42 to 1.50, depending on the speed.

It has sometimes been doubted whether the coefficient C of a given Pitot tube was dependent solely on the relative speed of the fluid and the tube, the suggestion being that a tube standardized by moving through a quiescent medium, as with a whirling arm in air, may not give correct results when used to determine the velocity of a fluid past a fixed point. It is difficult to see how the Pitot tube can respond to anything but velocity relative to itself. At all events, experiments by Fry and Tyndall have shown that while there was some apparent disagreement at speeds below 11 miles per hour (17.7 kilometers) where the experimental errors were large, for higher speeds, up to 36 miles per hout (58 kilometers) both methods of standardization gave the same result.

Which method of standardization should be adopted - motion of the tube or motion of the fluid - may, nevertheless, depend on the purpose for which

the instrument is intended. It is impossible in practice to set up an artificial current of fluid which shall have a high speed and not be turbulent and full of eddies; and the only conditions to which equations (1) and (2) refer are, in strictness, those of steady stream-line flow or steady motion of the tube in a quiescent fluid. If the tube is to be used in a very turbulent medium, as, for example, in measuring the discharge from a fan, it should be standardized in a stream of fluid in which the turbulence is about the same as it will be under the working conditions. It might very well happen that a given tube when tested on the whirling arm or by moving through still water gave a coefficient C = 1, while if the tube were tested in a turbulent current some other value of C was obtained. If the tube were to be used to measure the average speed of a similarly turbulent current, this second coefficient should be used and not the value C = 1.

Apparent errors and inconsistencies in the results obtained by equations (1) and (2) have probably been due in part to disregarding the forego-

ing obvious considerations.

WORKING FORMULAS FOR PERFECT PITOT TUBES:

It will be convenient to collect here, for reference, certain practical working forms of equation (3) for the perfect or ideal Pitot tube, that is, for a tube having the coefficient C equal to unity. If the tube does not satisfy this condition, whether on account of its design or from the necessary circumstances of practical use, the value of C must be determined by experiment, and the values of S given by the following equations are then to be multiplied by the observed values of C.

We start by inserting the value g = 32.17 ft./sec.^{2} or 9.81 m./sec.^{2} in the general equation (3), viz:

$$S = \sqrt{2gh\frac{d}{p}} \qquad (3)$$

In which S = the speed of the current,
h = the head on the different gauge,
d = the density of the liquid in the gauge,
p = the density of the current.

From this we obtain special equations for practical use.

(A) Any two fluids.-d and p may have any values

but are to be measured in the same units. The value of S is given by the equation

$$S = X\sqrt{h\frac{d}{p}} \qquad (4)$$

with the values of X shown in Table 2 for various methods of expressing S and h.

(B) Any moving fluid, gauge liquid water.- The value of S is given by the equation

$$S = Y\sqrt{\frac{h}{p}} \qquad (5)$$

with the values of Y shown in Table 3

When the Pitot tube is to be used in air, the air density p for use in equations (4) and (5) may be found as follows:

Let B = the barometric pressure.

Let t = the temperature of the air.

Let P = the pressure of saturated steam at t^{0}, from the steam tables.

Let H = the relative humidity.

Then in English units, if B and P are in inches of mercury and t in degrees F.,

$$p = 1.327\ \frac{B-0.376P\ H}{460 + t}\ \text{lbs./ft.}^{3} \qquad (6\ )$$

or in metric units, if B and P are in millimeters of

TABLE NO. 2.

VALUES OF X FOR EQUATION (4).

h measured in-	S measured in-	X
Inches of liquid of density d ..	(Ft./sec.	2.316
	(Ft./min.	138.9
	(Mile/hour	1.579
Mm. of liquid of density d	(M./sec.	.1411
	(M./min.	8.404
	(Km./hour	.5043

TABLE NO. 3.

VALUES OF Y FOR EQUATION (5).

h measured in-	p measured in-	S measured in-	Y
Inches of water at 68° F. = 20° C.	Lbs./ft.^{3}	(Ft./sec. ...	18.28
		(Ft./min. ...	1097
		(Mile/hour ..	12.46
Mm. of water at 68° F. = 20° C.	Kgm./m^3	(M/sec.	4.426
		(M/min	265.5
		(Km/hour	15.93

****

mercury and t in degrees C.,

$$p = 0.464 \frac{B - 0.376PH}{273 + t} \text{ kgm./m.}^3 \qquad (6a)$$

All the numerical data given in this section are accurate enough to permit of computing the speed to within 0.1 per cent. Actual values computed from equation (6) may be found from Table 9 The calculations required by equation (6) may be avoided by the use of diagrams given by Rowse and Taylor. Hinz gives a diagram showing the gas constant of moist air, which may be used in place of equation (6a).

ERRORS OF THE PITOT TUBE AT VERY HIGH SPEEDS:

The theory of the action of the Pitot tube, shows that the equations given in the preceding sections must be expected to require a correction if the observed pressure difference is enough to compress the fluid sensibly. This will never occur when liquids are in question, though when the instrument is used for measuring the

speed of a gas the correction required to allow for compressibility might become sensible at high speeds. But for the highest speeds attained by aeroplanes, say 130 miles per hout, the correction computed from the theory is less than 0.5 per cent., an amount which is altogether negligible in comparison either with the errors of observation or with the uncertainties of the theory itself, which is far from convincingly rigorous.

GENERAL REMARKS ON RESISTANCE ANEMOMETERS:

When a fixed obstruction is placed in a current of fluid, it experiences a force in the direction of flow which depends upon and may be used as a measure of the speed of the current. The force depends on the relative motion and is the same, at the same relative speed, when the fluid is at rest and the body moves through it, the force then appearing as a resistance to the motion. It is the resultant of forces exerted on the elements of the surface of the body (a) normally by the pressure, which varies from point to point; and (b) tangentially by skin friction of the fluid moving

along the surface. Since we are now interested only in devices which may be used as anemometers, we may as well, for the future, say "air" instead of fluid, and "wind" instead of current.

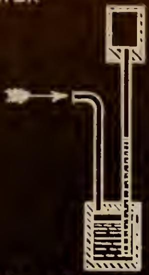
As regards the pressure, there is always on the windward or upstream side, a region of increased pressure, i. e., of excess above the general static pressure of the air; while on the leeward or downstream side there is a deficiency. In the Pitot tube, the obstruction consists of the impart tube with its open mouth at the upstream end. This receives the excess pressure and transmits it to the gauge. The instrument deals solely with the excess pressure on the upstream side, of an obstruction of particularly simple form, the drag due to skin friction and the suction on the downstream side having no effect on the reading of what we have called a perfect Pitot tube.

The next simplest case is that of a thin flat plate of regular outline set normal to the wind. The skin friction forces balance one another and the whole normal force on the plate is the surface

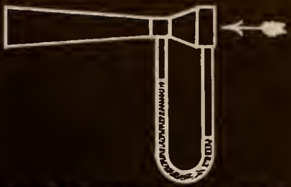
integral of the excess of pressure on the front, over that on the back. If the plate is mounted so that the force of the wind on it can be measured, it constitutes a "pressure-plate anemometer."

Various devices which are in practical use may be regarded as intermediate between the Pitot tube and the pressure plate anemometer. Among these are the Dines tube (see figure 10), the "Stauscheibe," and the Pneumometer. The Stauscheibe is a metal disk about 1 cm. in diameter with holes in the centers of its two faces from which the pressures are led to the two arms of the U gauge, through the disk and through the support by which the disk is held perpendicular to the current. The Pneumometer differs from the Stauscheibe only in details of construction. For both these instruments the coefficient of equation (1) has the value 0.854, the observed pressure difference being influenced by the suction at the downstream face as well as by the impact pressure on the upstream face.

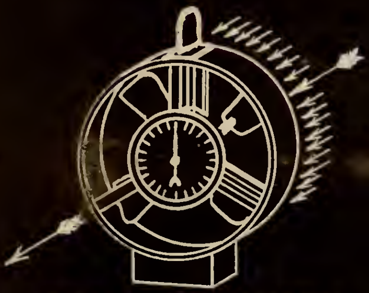
In the case of pressure plate anemometers, it is usually the total force acting on the ob-



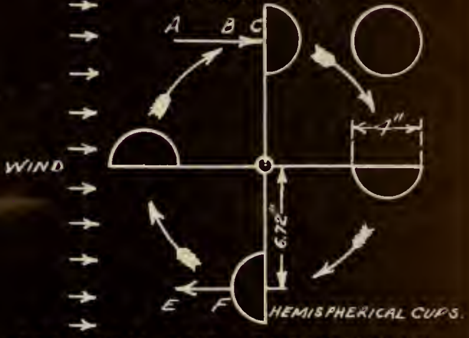
DINES ANEMOMETER
FIGURE 10.



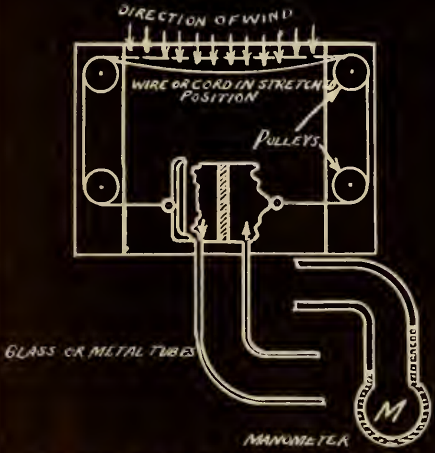
BOURDON-VENTURI ANEMOMETER
FIGURE 11.



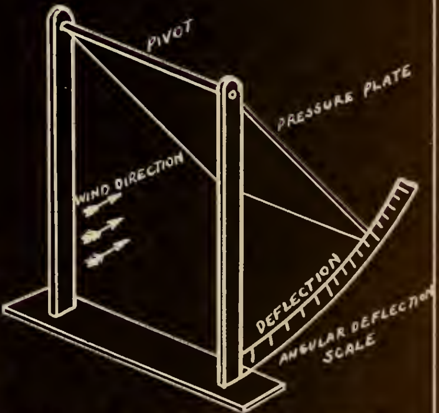
BIRAM'S ANEMOMETER
FIGURE 12.



ROBINSON CUP ANEMOMETER
FIGURE 13.



PRESSURE-TENSION ANEMOMETER
FIGURE 14.



PRESSURE PLATE ANEMOMETER
FIGURE 15.

struction in the wind that is measured, rather than a manometric pressure, although Stanton used a diaphragm and air pressure to transmit the force acting on a plate to a manometer 50 feet away.

If the solid obstruction is anything else than a thin flat plate normal to the wind, skin friction as well as pressure contributes to the resultant force; and if the body is not symmetrical about an axis parallel to the wind, the resultant force will not in general be parallel to the wind, but the body will receive a side thrust in addition to the resistance in the direction of the wind, as, for example, when the wing of an aeroplane has both lift and drift. Any body mounted so that the force on it can be measured,provides a means of measuring the speed of the wind and may be used as an anemometer; but if the body is to be held in a fixed orientation with respect to the wind, it is evidently simplest, mechanically, to avoid side thrust by making the body symmetrical about the wind direction, preferably a figure of revolution about that axis. The resistance offered to the wind by a

symmetrical body of given maximum section normal to the wind depends greatly on its shape, being less for a sphere than for a flat plate normal to the wind, and still less for a somewhat elongated spindle-shaped body.

Whatever the shape of the body may be, unless it is a sphere its resistance to a given wind depends on its presentation, and by a suitable choice of shape this variation of the force with the orientation may be made quite large. The operation of the Robinson, or cup anemometer, depends on the fact that the resistance of a hemispherical cup is greatest when the concave side is pointed to windward, so that a wind blowing in the plane of rotation of the always produces a torque. In the so-called "bridled" form of this anemometer, the torque is measured statically and the instrument is then merely a rather complicated form of pressure-plate anemometer. In the ordinary form of the instrument, in which the cups are allowed to revolve freely, the speed of the wind is measured indirectly by observing the speed of rotation, the action of the wind on the cups

being then still more complicated.

From the fact that the pressure recorded by the Pitot tube is proportional to the square of the speed, it might be surmised that the total force observed with a pressure-plate or other static resistance anemometer would probably also be nearly proportional to the square of the speed; and this is confirmed by experiment. The analogy between these anemometers and the Pitot tube is a very close one, the Pitot tube being in principle only a particularly simple kind of resistance anemometer.

We have next to speak somewhat more in detail of some special types of resistance anemometer.

THE WIND RESISTANCE OF FLAT PLATES:

The resistance of a flat plate normal to a wind of velocity S is nearly proportional to S^2 and this relation is sometimes represented by writing

$$P = K S^2 \qquad (7)$$

in which P is the force per unit area of the plate. The coefficient K is approximately proportional to the density of the air, but it varies with the size

and shape of the plate. The independence of Pitot tube readings of the size and nature of the dynamic opening would lead us to expect that the pressure at the center of the front of the plate would be independent of the size and shape of the plate, and Stanton's experiments confirm this expectation. But the suction on the back depends on size as well as speed, thus accounting for the variability of K and showing that P is only a fictitious pressure with no physical significance.

We shall confine our attention to square and round plates, for which the laws of the distribution of pressure are more simple than for very oblong rectangles. When giving numerical values in "English units" pressure will be in pounds per square foot and speeds in miles per hour, while in "Metric units" pressure will be in kilograms per square meter and speeds in meters per second.

A. Square plates.- According to Eiffel the value of the coefficient K of equation (7) in English units varies from 0.00266 for plates 4 inches square to K = 0.00326 for plates 40 inches square or

larger. The temperature and pressure of the air during the tests are not given. The corresponding metric values are 0.065 and 0.08. Bairstow and Booth after analyzing the available data give the equation

$$F = 0.00126\ (S\,l)^2 + 0.0000007\ (S\,l)^3$$

in which F is the total force in pounds, S is the speed in feet per second, and l is the length of side in feet. The equation refers to air at 760 mm. and 15° C. or 59° F. If S is measured in miles per hour the equation becomes

$$F = 0.00271\ (Sl)^2 + 0.0000022\ (Sl)^3$$

and if put into the form (7), for the sake of comparison with Eiffel's results, it may be written

$$P = 0.00271(1+0.0008\ Sl)S^2$$

the coefficient K depending on both S and l.

B. Circular disks.- For a circular disk 30 centimeters, or 11.8 inches, in diameter, Eiffel gives the value K = 0.00276 English, or 0.0675 metric. Stanton found the values K = 0.0027 English (0.066 metric) by using a 2-inch disk. On the whole, Eiffel's results seem prefer-

able, because the size of disk used by him is more nearly the desirable size for an anemometer.

As regards the relative importance of the front and back of the plate, it may be noted that in a wind 10 meters per second or 22.4 miles per hour, Eiffel found that the front of his 12-inch disk accounted for 72 per cent of the whole resistance. Zahm has pointed out that if a plate be surrounded by a sufficiently broad guard ring there will be no suction on the back, while the pressure on the front will be uniform and the same as indicated by a Pitot tube at the same speed.

Table 4 shows the force on a 12-inch disk for different wind velocities, the total resultant force being calculated from Eiffel's value of K = 0.00276 English (0.0675 metric), and from Bairstow and Booth's formula for square plates, assuming, as some but not all experimenters have found, that the average pressure would be the same for a circular plate with a diameter equal to 1, as for a square of side 1.

TABLE NO. 4.

WIND FORCES IN POUNDS ON A 12-INCH DISK.

Wind speed S miles per hour.	Force in pounds according to Eiffel.	Force in pounds according to Bairstow and Booth.
30	1.94	1.97
40	3.47	3.50
50	5.40	5.53
60	7.80	8.00
70	10.60	11.01
80	13.88	14.48
90	17.55	18.48

TABLE NO. 5.

WIND FORCES IN KILOGRAMS ON A 30-CENTIMETER DISK.

Wind speed S kilometers per hour.	Force in kilograms according to Eiffel.	Force in kilograms according to Bairstow and Booth
48.3	0.86	0.87
64.4	1.53	1.55
80.4	2.38	2.44
96.5	3.44	3.53
112.8	4.68	4.87
128.8	6.13	6.39
145.0	7.75	8.15

****

RESISTANCE OF SPHERES AND HEMISPHERES:

Next to thin plates and hemispherical cups the sphere has been most frequently employed in static resistance anemometers as the obstruction opposed to the wind. In addition to the fact that a sphere is symmetrical about all diameters, so that the indications of a sphere anemometer may be made independent of changes in wind direction, the sphere has the further advantage of simplicity of form so that it may readily be duplicated. A disadvantage of the sphere, as compared with thin plates, is the lower value of the coefficient K of equation (7).

According to W. H. Dines, as quoted by Lanchester, K gas a value of 0.00154 English for a sphere 6 inches in diameter, or 0.0378 metric for one 153 millimeters in diameter, Dines's tests were made with a velocity of 21 miles an hour (34 kilometers). Eiffel gives K as 0.00045 (0.011 metric) and explains the difference between his value and that of 0.00112 (0.0275 metric) found at Göttingen, as follows: K decreases with an

increase of velocity until a certain critical velocity is reached, after which K remains nearly constant at 0.00045 for the three spheres experimented upon. This critical velocity was found to be about 27 miles an hour for a 6-inch sphere, 16 miles for a 10-inch sphere, and 9 miles for a 13-inch sphere (12, 7, and 4 meters per second, respectively, for the 16, 24, and 33 centimeter spheres). The high value of the Göttingen coefficient is, according to Eiffel, due to the fact that velocities of over 23 miles an hour (36 kilometers) can not be obtained at that laboratory. It will be noted that even for a 6-inch sphere the critical velocity is well below the lowest flying speeds used in practice.

Table 6 shows values of K for hemispherical cups, according to Dines. Since Dines used only the one speed of 21 miles an hour, there is a doubt whether his values would hold for higher speeds. It appears that with a cup there would be little if any reduction in diameter as compared with a plate giving an equal force, though the cup

TABLE NO. 6.

VALUES OF K IN EQUATION (7) FOR HEMISPHERICAL CUPS.

	English	Metric	English	Metric	English	Metric
	Diameter of cup.					
	2½ in.	64mm.	5 in.	127mm.	9 in.	229mm.
Cup facing wind	0.00597	0.146	0.00386	0.095	0.00402	0.099
Cup with back to wind	.00239	.059	.00168	.041	.00138	.034

****

would have the advantage of greater strength for a given force and weight. The difference in the force acting on the cup in its two positions, which is the driving force of the Robinson anemometer, is clearly indicated by the table.

PRACTICAL FORMS OF RESISTANCE ANEMOMETER:

Maxim used a pressure plate anemometer consisting of a disk with a spring resistance. His arrangement had the advantage of fairly uniform graduations of the scale, the spring acting indirectly, with variable leverage on the pressure plate.

In the pressure-plate anemometer of Dines the variable resistance is furnished by a float partly immersed in water, the pressure on the plate being equal to the weight of a volume of water equal to that of the part of the float raised above the water level.

The 1914 catalogue of Aera, Paris, shows a pressure plate anemometer which is merely a speed indicator. It is supplied with three disks, so that it may be set for any speed between 50 and 75

miles an hour (80 and 120 kilometers). The pointer will then show whether the actual speed is above or below the normal. Aera also make an anemometer using a sphere, in the form of a pendulum. This instrument reads only to 45 miles an hour (72 kilometers) and has graduations coming closer together at higher speeds. It would be very inaccurate without some means for holding it vertical.

The Davis Lyall air speed indicator, made by John Davis & Son, of Derby, England, is a bridled anemometer of the screw type which should be held with its back to the wind, though the manufacturers do not provide it with an air vane to do this automatically. This defect is rendered in the Aera bridled anemometer. Concerning the Davis Lyall instrument, it is stated:

"To avoid undue oscillation of the pointer a damper is provided - either magnetic or air. Such a damper is rendered necessary in measuring velocities in a natural wind which varies within wide limits."

When it is desired to investigate the gusty

character of natural winds, the sensitiveness of a bridled anemometer becomes an advantage. Concerning a bridled anamometer consisting of five hemispherical cups attached to a vertical spindle by short arms, Stanton says that this instrument is more sensitive to momentary gusts than any of the other recording instruments in common use.

THE ANEMO-TACHOMETER:

When anemometers of the screw type are used for high velocities there is danger that the vanes will be deformed and the velocity indications become unreliable, and for this reason cup anemometers are more suitable for out-door work. Wilhelm Morell, of Leipzig, has placed on the market an anemo-tachometer illustrated in the Deutsche Luftfahrer. This is a Robinson anemometer with tachometer attached for aeronautical purposes, the tachometer being an instrument,usually actuated by centrifugal force like a steam engine flyball governor, so that velocities may be read at a glance from the position of a pointer. It will be noted that with a tachometer, in contrast to a revolution

counter, no measurement of a time interval is required. The anemo-tachometer also has the advantage of all Robinson anemometers that the wind vane may be dispensed with.

According to a communication from Morell, his anemometers are calibrated in a wind tunnel, built in accordance with designs of Prof. Prandtl of the University of Göttingen, in which air currents up to 78 miles per hour (125 kilometers), can be obtained. It is stated that some of these instruments have been in constant use for two years without needing recalibration.

The anemo-tachometer, as well as other anemometers, should be attached to the aeroplane in such a manner that its indications are not influenced by the irregular and indeterminate wash of the machine and propeller. It has been proposed to lengthen the distance between the cups and the casing, so as to bring the cups above the upper supporting plane, while keeping the dial on a level with the pilot's line of vision. The objection to this lengthening is that it might change the friction

and hence the indications of the instrument, and necessitate a special calibration.

What appears at first sight to be a solution of the difficulty, would be to provide the anemometer axis with a small electric generator, and use the electric voltage, thus generated to indicate speed of rotation by means of a voltmeter. We should anticipate, however, that electric indicating instruments as at present constructed, would not long retain their accuracy when exposed to the vibrations on an aeroplane.

THE BOURDON-VENTURI ANEMOMETER:

The Venturi tube consists of a short converging inlet followed by a long diverging cone, the entrance and exit diameters being usually equal so that the tube may be inserted as a section of a pipe line. There is generally a short cylindrical throat. The converging part has somewhat the shape of a vena contracta, but its exact form is of little importance. The exit cone has a total angle of about 5°, this being found to give the minimum frictional loss for a given increase of diameter.

When a current of fluid passes through the tube, the pressure in the throat is less than at extrance to the converging inlet, by an amount which depends on the ratio of entrance to throat area, the density of the fluid, and the speed of flow. If the tube is provided with side holes and connections to a differential gauge by which this pressure difference may be observed, it constitutes a Venturi meter. The area ratio is a known constant for a given tube, so that when the density of the fluid is known the observed pressure difference may be used as a measure of the speed of flow. When the pressure difference is expressed as the height of a water column, it is known technically as the "head on Venturi."

Such an instrument may be used as an anemometer by pointing it so that the wind blows directly through it, and the observed head may then serve as a measure of the wind speed. Bourdon employed the Venturi tube for this purpose in 1881, and it has been used recently as an aeroplane anemometer.

At a given speed, the observed head

increases with the ratio a of entrance to throat area and the instrument may be made to give a much larger head than a Pitot tube. This is illustrated by the figures given in Table 7 for a tube in which a = 4, the throat having half the diameter of the entrance. The data are for air at atmospheric pressure and 70° F. Column (2) gives the head which would be observed with a Pitot tube; column (3) that observed by Bourdon; and column (4) the ratio of (3) to (2).

Since Bourdon wanted an anemometer for very low speeds, he increased the available head still farther by using two concentric tubes, the exit end of the inner one being at the throat of the outer, so that the suction there increased the speed through the inner tube and the fall of pressure at its throat. The proportions of the tubes which were adopted as giving the best results were as shown in Table 8.

No cylindrical throat piece was used with either tube, the converging and diverging cones being connected directly.

TABLE NO. 7. - COMPARISON OF PITOT AND VENTURI HEADS OF a = 4.

(1) Wind speed.		(2) Pitot-tube head.		(3) Head on Venturi according to Bourdon.		(4) $\frac{\text{Col. 3.}}{\text{Col. 2.}}$	(5) Theoretical head on Venturi.	
Miles hour.	Meters sec.	Ins.	Mm.	Ins.	Mm.		Ins.	Mm.
10	4.47	0.05	1.3	0.17	4	3.4	0.7	18
20	8.94	.19	4.8	.80	20	4.2	2.9	74
30	13.41	.43	10.9	2.30	58	5.3	6.8	173
40	17.88	.77	19.6	4.0*	102*	5.2	12.3	312
50	22.35	1.20	30.5	6.6*	168*	5.5	20.0	508
60	26.82	1.73	43.9	10.0*	254*	5.8	30.0	762
70	31.29	2.35	59.7	15.0*	381*	6.4	45.0	1,143
80	35.76	3.07	78.0	20.0*	508*	6.5	63.0	1,600
90	40.23	3.89	98.8	25.0*	635*	6.4	90.0	2,286

* * *

Bourdon also used a similar arrangement of three concentric tubes. The heads obtained with this, at various wind speeds, are shown on figure by the curve D C and by the isolated point A. The point B is from tests of a 3-tube instrument by Brown Boveri & Co.

The proportions of single-tube anemometers as used in modern French practice seem to be somewhat like those of Bourdon's inner tube. (See Table 8). The length of tube in the anemometer made by Aera, of Paris, is 6.3 inches (160 mm.) or nearly the same as the length of the diverging cone of Bourdon's inner tube. Dorand gives, without dimensions, a section of a Venturi-tube anemometer which indicates a ratio of throat to entrance diameter of about 0.2. The proportions proposed by Toussaint and Lepere as a result of recent experiments are very similar to those of Bourdon 's outer tube. (See Table 8).

REMARKS ON THE SPECIAL CONDITIONS TO WHICH AEROPLANE ANEMOMETERS ARE SUBJECT:

A. Weight and head resistance. - These must

TABLE NO. 8.

PROPORTIONS OF BOURDON'S DOUBLE VENTURI TUBE ANEMOMETER.

	Inner tube.	Outer tube.
Ratio of minimum to maximum diameter:		
(a) Of converging cone...........	0.31	0.56
(b) Of diverging cone	0.45	0.60
Double angle:		
(a) Of converging cone	34° 15	21° 38
(b) Of diverging cone	3° 45	4° 50
Relative throat diameters	1. 0	6.2

TABLE NO. 9.

Relative density D of air at B inches pressure, t° F., and 50 per cent. relative humidity, referred to air at 29.92 inches pressure, 70° F., and 50 per cent. relative humidity.

B =	20"	22"	24"	26"	28"	30"
t = 0° F.	0.773	0.851	0.928	1.006	1.083	1.160
10°	.757	.833	.908	.984	1.060	1.135
20°	.741	.815	.889	.963	1.037	1.112
30°	.725	.798	.871	.943	1.016	1.088
40°	.710	.781	.853	.924	.995	1.066
50°	.696	.766	.835	.905	.975	1.045
60°	.681	.750	.818	.887	.955	1.023
70°	.667	.734	.801	.868	.935	1.003
80°	.653	.719	.785	.850	.916	.982
90°	.639	.703	.768	.833	.897	.962

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both be small - the smaller the better. Accordingly we need not consider any essentially heavy instrument, such as those which require the use of many electric batteries, nor instruments like large pressure plates which offer a head resistance of several pounds.

B. Robustness.- The very severe conditions of vibration preclude the possibility of using instruments which are not mechanically strong or which can not be made so without too great weight. Both the anemometer head proper, and the transmitting and indicating parts must be simple, light, strong, and free from the need of delicate adjustment or frequent testing.

C. Position.- The head must, so far as practicable, be out of reach of irregular currents and eddies and therefore at some distance from the indicator or dial in front of the pilot. The available positions are (a) in front of the center of the machine, (b) well above the upper planes over the pilot's head, (c) near one wing tip. Position (a) might be practicable and satisfactory in some cases

but there is a possibility, unless the head were very far in front, that the readings might not be the same, at a given speed, during normal flight as when planing with the motor stopped. We have no information on this point. The influence of the body extends some distance ahead, a fact which should not be overlooked. Position (b) would often require the construction of a special support, increasing the weight and head resistance. Position (c) seems the natural one to adopt if a transmission of the requisite length can be made satisfactory; but here again it should be noted that the disturbance due to a strut or wing begins some distance ahead of the leading edge.

D. Orientation.- While most anemometers have to be pointed directly into the wind if they are to indicate its resultane velocity, what is needed in aviation is primarily the relative wind speed along a direction fixed with regard to the axis of the machine. The undesirable complication of mounting the anemometer head on a wind vane is therefore unnecessary and the head may be fixed. If information is required about motion perpendicular to this

direction, it may be obtained from a wind vane.

E. Independence of gravity.- On account of the very considerable angles of heeling and pitching, it seems useless to consider any instrument which depends for its action on weights or liquid manometers. Any required forces must be applied by springs; or if pressures are to be registered, it must be by spring gauges. Furthermore, all parts of the instrument must be so balanced that the readings are not affected at all by gravity. This remark applies to the transmission and the indicator as well as the head.

F. Vertical acceleration and centrifugal force.- Vertical acceleration acts merely as a change of the intensity of gravity. It will, therefore, have no effect on an instrument which is properly constructed in accordance with E, above.

Centrifugal force must be allowed for in a similar way by careful balancing of all movable parts so that the lateral acceleration of the whole machine during curved flight shall not influence the readings. This balancing in the transmission is equally necessary,

whether forces are transmitted by rods or wires or pressures by fluids in tubes.

DENSITY CORRECTIONS:

Before considering the effects of changes of air density on the indications of particular types of anemometer it will be well to see how great these variations are likely to be under working conditions. For this purpose we consult equation (6), viz,

$$p = 1.327 \frac{B - 0.376\ PH}{460 + t} \qquad (6)$$

in which

p = the density of the air in pounds per cubic foot.

B = the barometric pressure in inches of mercury.

t = the temperature of the air in degrees Fahrenheit.

P = the pressure of saturated steam at t° in inches of mercury.

H = the relative humidity ($H = 1.0$ for saturated air).

The ranges we shall assume are: $B = 30$ to 20 inches, corresponding to a rise from sea level to about 10,000 feet altitude; $t = 0^{\circ}$ to 90° F.;

$H = 0.0$ to 1.0, i. e., from complete dryness to saturation.

We may first consider the term $0.376\ PH$. Taking P from the steam tables we have

at $t =$	50°	70°	90°
$0.376\ P =$	0.136	0.278	0.533
$0.376\ P \times 0.5 =$	0.068	0.139	0.267

If we assume a constant relative humidity $H = 0.5$, while in fact the humidity varies all the way from 0.0 to 1.0, the maximum error we can make in the value of $0.376\ PH$ is $0.376\ P \times 0.5$, of which the values at 50°, 70°, and 90° are shown above. To find the percentage error which this assumption can introduce into the computed value of p we must compare these errors with the value of B. The following table shows the maximum per cent. errors in p at 50°, 70°, and 90° F. and at 20 and 30 inches pressure which can be caused by assuming $H = 0.5$.

	$t = 50^\circ$	$t = 70^\circ$	$t = 90^\circ$
$B = 20$ inches	0.34%	0.70%	1.33%
$B = 30$ inches	0.23%	0.46%	0.89%

Since a temperature of 90° F. will seldom or never prevail at an altitude where the pressure is

as low as 20 inches, we may regard 1 per cent. as about the maximum possible error, and in the vast majority of cases the actual error will be less than 0.5 per cent. Now with the anemometers we need to consider, a given percentage error in the density causes only about half as much error in the speed S; and furthermore, an accuracy of 1 per cent in measuring the speed of an aeroplane may be regarded as satisfactory. Hence the assumption of a constant relative humidity of 50 per cent. ($H = 0.5$) is quite approximate enough for our purpose, and we adopt this assumption and thereby simplify equation (6) to the form

$$p = 1.327 \frac{B - 0.19\ P}{460 + t} \text{ pounds per cubic foot.} \quad (8)$$

From equation (8) we may now compute a table of approximate values of the air density at various values of the barometric pressure B and the temperature t. It will be convenient to have the values expressed, not in pounds per cubic foot, but in terms of a standard air density, and for this the value = 0.07455 has been chosen. This is the density at $B = 29.92$ inches, $t = 70^\circ$ F., and $H = 0.5$, conditions which are a

fair average representation of those which are likely to prevail during anemometer tests. The values are shown in Table 9.

We have next to consider how these variations of density may affect the readings of an anemometer which has been tested under standard conditions.

A. The Pitot tube.- The Pitot tube formula may be written

$$S = \text{const} \times \sqrt{\frac{p_1 - p_2}{p}}$$

or for a standard density p_o

$$S_o = A_o \sqrt{p_1 - p_2}$$

At any other density, $p = D_{po,}$ we have

$$S = \frac{A_o}{D} \sqrt{p_1 - p_2} = \frac{S_o}{\sqrt{D}} \qquad (9)$$

If the tube has been standardized at the density p_o and the constant A_o determined, or if the gage has been provided with a speed scale or a table for converting its readings at the standard density

p_0 into speeds, the true speed at any other density p is found by multiplying the indicated speed by $\frac{1}{\sqrt{D}}$. Values of $\frac{1}{\sqrt{D}}$ computed from Table 9 are given in Table 10.

If the purpose of reading the anemometer is not, primarily, to ascertain the speed, but to judge of the wind pressures on the machine which determine the lift and the stresses, then the density correction should not be applied. For at any given angle of attack, the wind forces are very nearly proportional to the Pitot pressure; when the gauge shows a given reading, the wind forces are always the same; and from the standpoint of sustaining power and strength it is immaterial how the forces arise. Hence from the point of view of the aviator who is concerned with the safety of his machine, the speed readings of the Pitot-tube anemometer correct themselves automatically - if the machine flies safely at a given speed and in air of a given density, it will be equally safe in air of any other density, regardless of pressure, temperature, and humidity

TABLE NO. 10.

VALUES OF $\frac{1}{\sqrt{D}}$ FOR USE IN EQUATION (9).

t° F.	Barometric height B in inches of mercury.					
	20"	22"	24"	26"	28"	30"
0.......	1.137	1.084	1.038	0.979	0.961	0.928
10	1.149	1.096	1.049	1.008	.971	.938
20	1.162	1.108	1.061	1.019	.982	.948
30	1.174	1.119	1.072	1.030	.992	.958
40	1.187	1.131	1.083	1.040	1.003	.969
50	1.199	1.143	1.094	1.051	1.013	.978
60	1.212	1.155	1.106	1.062	1.023	.989
70	1.225	1.167	1.117	1.073	1.034	.999
80	1.238	1.180	1.129	1.084	1.045	1.009
90	1.251	1.193	1.141	1.096	1.056	1.020

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if the Pitot-tube gauge gives the same reading.

B. Pressure-plate anemometer.- It would naturally be supposed that the readings of pressure plate anemometers would be affected by variations of air density in the same way as those of Pitot tubes. The theory of the subject, however, is not entirely clear, and it is difficult to interpret some of the experimental results which have been obtained. In the absence of further investigation it would seem safest to make the density correction, when necessary, exactly as is done for the Pitot tube. If the readings are taken only for the sake of estimating the wind forces on the machine, the density correction is to be omitted, just as with the Pitot tube.

C. The Bourdon-Venturi anemometer. - If the results of Bourdon's experiments agreed closely with computations from the theoretical equation of the Venturi meter, we should feel justified in using that equation to compute density corrections to be applied to the readings of an instrument which had been tested at a standard air density. But the dis-

crepancies shown by curves GH and EF of figure are so large that we can not trust the theoretical equation at all for a Venturi tube used as an anemometer. It appears that further experimental investigations of this instrument are needed.

D. Rotary anemometers.- Regarding rotary anemometers, Jones and Booth say:

"The principal advantage possessed by instruments of this type is that they read the actual travel through the air independently of variations in density."

It seems likely, however, that this independence is only approximate and not complete. The ratio of cup or vane speed to wind speed depends on the value of the least wind speed which will just keep the anemometer turning against friction. And since each vane or cup when moving very slowly acts as a pressure plate, it seems that the wind speed required in order to furnish the torque for very low speeds of rotation must depend on the air density. Hence it seems probable that at higher speeds the action of instruments of the Robinson or of the screw

type is somewhat influenced by air density. Exact information on this is lacking.

COMPARISON OF TYPES OF ANEMOMETER:

Anemometers in general might be compared from various points of view; but since our purpose is strictly practical, we shall at once exclude from the discussion any instrument which can not be made satisfactory on the score of (a) robustness combined with lightness, (b) independence of gravity, and (c) flexibility of transmission, permitting the head to be placed at a distance from the indicator in front of the pilot's seat. There seem then to remain for discussion the Pitot tube, the pressure plate, the Venturi tube, and the Robinson anemometer.

A. The Pitot tube.- This has been the most studied, and we can speak of it with more certainty than of the others. The head is simple and may be placed in any position; and the transmission of the pressure through tubes presents no obvious difficulties. the prime defect of the instrument is the smallness of the pressure available for actuating the indicator. While sensitive liquid gauges may be used under some

circumstances, anything but a spring gauge seems out of the question for all-round use. The problem with the Pitot tube is to make a satisfactory spring gauge which shall at the same time be sufficiently sensitive and so robust as to be reliable. The problem looks difficult, but may not be insoluble.

B. The pressure plate. - By an increase of size, the pressure plate may be made to give as large a force as is desired, the limit being set by the amount of head resistance which it is considered permissible to devote to an anemometer. Transmission by wires under tension might be practicable but would be liable to get out of order and to be seriously disturbed by vibration. Transmission by means of liquid pressure might be managed but would introduce complications, and the development of the instrument in this form would demand a great deal of experimentation. In spite of its attractiveness and apparent simplicity at first sight, the pressure plate does not, on the whole, seem very promising as a practical aeroplane instrument.

C. The Bourdon-Venturi anemometer. - The

Venturi tube furnished a pressure difference and the transmission problem is simple, as it is with the Pitot tube. But the pressure difference may be made so large that the problem of making a satisfactory spring gauge is vastly simpler than with the Pitot tube, and should not present any insuperable difficulties. A more important doubt arises in connection with the density correction. Since it is impracticable to test an anemometer at low-air densities by the ordinary methods, and since Bourdon's results differed greatly from what might have been expected on theoretical grounds, the instrument should be used with caution, if high altitude flights are in question, until we know more about its practical behavior. On the other hand, it appears to be satisfactory at ordinary air densities, and it seems to be an instrument of great promise and one of which the practical development should be pushed along.

D. The Robinson anemometer. - The weak point of the Robinson anemometer is lack of flexibility in the transmission. In the form of Morell's anemotachometer it indicates speed through the air nearly

independently of the air density. But since the main purpose of knowing this speed is for finding the total distance traveled, it would seem as if the ordinary method of registering the total number of turns would, in practice, be more useful than the attachment of a tachometer to give instantaneous speeds.

Having now discussed some of the mechanical characteristics of the four types of instrument we may take another standpoint and, assuming that a mechanically satisfactory instrument of each type can be constructed, ask whether one presents any advantages over another. The answer to this question depends on why we want to know the speed.

If what is wanted is to estimate the distance traveled through the air, some form of Robinson anemometer seems to be the thing to use, because it is independent of air density, to a first approximation, at all events. The other three types of instrument will all require to have a density correction applied to their readings, if the air density is far different from that during standardization, and they are thus at

a disadvantage.

But it appears that the speed through the air is, in general, not itself the important quantity sought; for at best it does not tell us the speed over the ground until it is compounded with the speed of the wind which may happen to be blowing. A more important use of the anemometer is not properly as a speedometer but as a dynamometer, i. e., as an instrument for indicating the air forces on the machine. For this purpose, any instrument such as the anemo-tachometer which gives the speed without reference to the density will require a density correction to its readings, whereas the Pitot tube gives just what is wanted, the allowance for density being already present in its uncorrected readings, so that equal readings mean equal pressures, whatever the density may be. The pressure plate falls in the same class as the Pitot tube. Of the Bourdon-Ventiru anemometer we can say very little until the instrument has been further studied, but it seems likely that it also will act rather as a dynamometer than as a speedometer, if its readings are not corrected for variations of air density.

Still another question which may be asked is, What sort of mean speed does a given anemometer indicate when exposed to a gusty wind? In regard to this question, the four types under consideration fall into the same grouping as before. With the Pitot tube, the pressure plate, or the Venturi tube, the pressure difference or the force depends on the square of the wind speed, and the mean reading of any of these instruments in a wind of varying speed will therefore give not the arithmetical mean speed but the root-mean-square speed, which is what determines the mean wind forces on the aeroplane. The anemo-tachometer, on the other hand, will probably indicate something between the arithmetical mean and the root-mean-square speed. If it had no inertia it might be made to indicate the arithmetical mean, but the effects of inertia in causing lag or lead will probably make the mean reading of the instrument in a wind of variable strength somewhat higher than it would be in the absence of inertia. The fact that this might result in a slight overestimate of the total travel will hardly be of any moment, in view of

the impossibility, for the aviator, of measuring and allowing for the true velocity of the wind with respect to the earth's surface.

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ANEMOMETER CALIBRATING TESTS.

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When we employ a given instrument to measure the motion of the wind, the instrument is set up in a fixed position while the wind under measurement blows past it. If now, we could independently ascertain satisfactorily the velocity of the wind during any given interval, it would be a simple matter, from suitable observations under such circumstances to determine the law by which to convert the readings of the instrument into the speed of the wind. Such a method of testing anemometers, however, is not in a broader sense, available, because; (1) we have no means of accurately measuring the speed of the wind, except by some other anemometer which must itself be first calibrated or tested, and (2) because such experiments do not in general, conveniently afford the range of velocities ordinarily desired. Experiments of this kind, are in fact simply comparisons between two or more instruments.

In the face of these difficulties, those who have sought to solve this problem have been led to adopt the expedient of moving the instrument to be calibrated at the desired velocity or velocities through comparatively still or quiet air. In these cases it was naturally assumed that the moving anemometer in still air will behave in every way like the stationary anemometer in moving air. In the older experiments made by this method, the instrument was placed on the free end of a horizontal arm arranged to revolve on a vertical shaft or axis. The anemometer could thus be made to pass in a circular path through relatively still air.

Various difficulties arise in carrying out experiments by this method, all more or less directly due to confining the motion of the anemometer to a circular path of comparatively small diameter. When this was recognized some efforts were made to standardize particular types of anemometers under conditions of straight line motion, such as that afforded on locomotives or specially prepared cars running at various speeds across the open country.

While this,no doubt, obviates the difficulties of curvilinear motion, others of greater consequence are introduced; for example, it appears quite probable that the excessive vibration characteristic of certain railway trains in rapid motion has an appreciable effect on the friction of most forms of anemometers. Moreover, the difficulty of making due allowance for the natural wind that may be blowing at the time is a very serious one so that results by this method have thus far scarcely equalled in accuracy those otherwise obtained.

As early as 1888 Professor C. F. Marvin of the U. S. Weather Bureau, undertook a series of tests of the standard anemometers (Robinson Cup Anemometers) employed to measure wind velocity at Weather Bureau stations, and, for this purpose, designed a whirling machine of unusually large dimensions. The maximum length of the arm was 35 feet, measured from the center of the vertical axis to the anemometer axis. At that time it was aimed to conduct the tests in perfectly still air, or at least as nearly still as could be obtained, and to this end

experiments were made at night time in the great closed court of Pension Building, which afforded ample space for the whirler, large as it was. An extensive series of experiments was carried out under these conditions of steady, uniform, motion over a circular path of large diameter and through practically still air. Anemometers of various dimensions, as well as the standard type, were tested with closely concordant results. When, however, these instruments were afterwards compared in open air, systematic differences immediately developed, and it was soon discovered that a new factor, not previously considered, must be recognized in conducting anemometer tests; namely, that owing to the inertia of the revolving parts of the ordinary instrument, a steady wind will cause it to give a different indication than will result in a "gusty" wind of the same average velocity. By the word "gusty" is understood, - characterized by marked sudden, and irregular changes in velocity. All natural winds, as far as they have ever been analyzed, prove to be extremely variable, or in other words, gusty. This

being the case it was therefore, a mistake to aim to secure perfectly steady motion in still air during the whirling arm experiments, since, as the instruments were intended for use in the gusty, open-air winds, the artificial test winds should also have been gusty to a corresponding degree. The whirling machine having been necessarily dismantled before the above stated principle was brought out, further experiments in this direction could not be conducted, but the results of the tests of the standard Weather Bureau anemometer were reduced to open air conditions; that is, to gusty winds by means of comparisons with small anemometers of slight inertia.

As a secondary result of the researches referred to, it is the writer's opinion that, with proper precautions anemometer tests are best made by the use of a large whirling machine, and for Weather Bureau instruments, freely exposed in the open air. For anemometers of the electrical hot-wire type, calibration by means of a rotating disc seems to present many advantages and is very accurate.

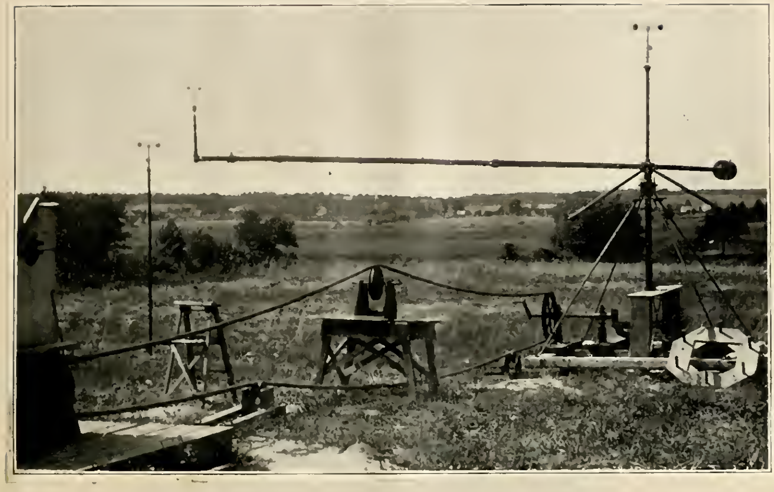
For wind measuring anemometers of the out-door type, the experiments should be made while there is more or less natural wind blowing. It is necessary only to seek a free and open exposure so as to avoid local and abnormal peculiarities in the natural wind, and to deal with a large number of experiments so as to eliminate the large accidental irregularities. The presence of the natural wind has the effect of alternately adding to and subtracting from the artificial wind resulting from the steady motion of the whirler, so that the actual resultant wind affecting the anemometer thereby acquires a gusty character with a maximum and minimum velocity once in each complete turn of the whirler. This resultant velocity is made still further irregular by the variations in the natural wind. The artificial gusty wind thus secured affords a highly appropriate test wind for anemometers that are to be used in the open air.

Before describing the calibrating arm designed and constructed by the author, it may be of interest to describe that of Professor Marvin and

used by him as early as 1888. Figure A shows clearly the general appearance of the machine. The slender horizontal arm was made up of sections of standard wrought-iron pipe, of which the central piece was 2½ inches nominal inside diameter. The distance from the central axis to the axis of the anemometer was 28.01 feet or 8.54 meters. In the experiments of 1888 it was demonstrated that this length was ample to eliminate the more serious defects of circular motion, and it was adopted because it leads to a very simple and convenient mathematical relation employed in computing the velocity at the outer extremity of the arm. The equations are given further on. Originally the whirler was driven entirely by hand power, but later a long rope-belt connection was made with the small steam engine employed to run an automatic kite reel. Thirty-five miles an hour was about the highest velocity that could be given the anemometer by hand power. With the small steam engine a velocity at the end of the arm of nearly 60 miles per hour could be maintained.

The arrangement of the apparatus is shown in figure A . The anemometer being calibrated was one of the small type used on kites. Two other anemometers may be seen in the picture. These represent two methods that were employed to measure the natural wind movement during a calibration run. In the earlier tests this wind movement was deduced from the record made by an anemometer surmounting the central axis of the whirler. Since, in this case, the whole anemometer revolves with the fixed central axis of the whirler it becomes evident that when the anemometer cups and whirler revolve in the same direction the speed of the wind must be deduced from the sum of the turns or revolutions of the whirler and the recorded rotations of the cups, but from the difference of these when the directions of rotation are opposed to each other.

FIGURE A.



Whirling Arm Used in Marvin's Anemometer Tests.

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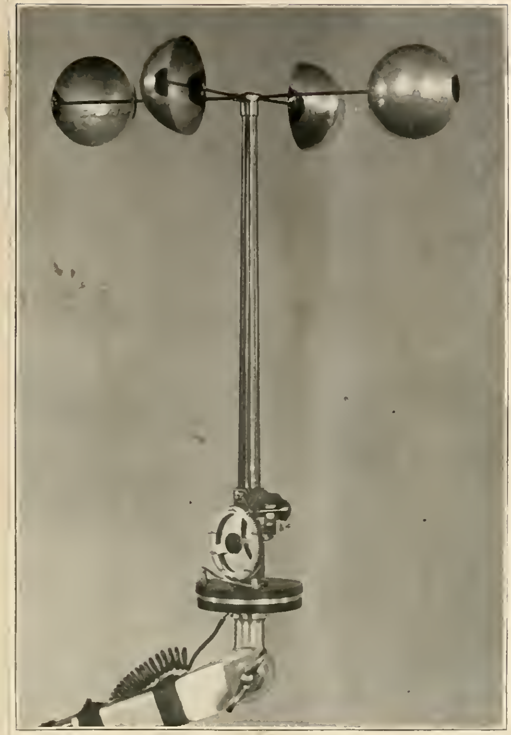
FIGURE B.



Small Cup Anemometer Attached to Spar Above Top of Kite.

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THE MEASUREMENT OF WATER FLOW.

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The Venturi Meter, as indicated by Figure 20 is a practical application of Bernoulli's theorem in which it is stated: At every section of a continuous and steady stream, the total energy is constant; whatever head is lost as pressure is gained as velocity. In terms of head this theorem may be expressed as follows:

Total Head = velocity head + pressure head + head due to elevation = constant; or in every stream section

$$H_T = h_v + h_p + h_e$$

$$= \frac{V^2}{2g} + \frac{p}{y} + h_e \quad \text{Feet}$$

where y is the constant necessary to reduce pounds per square inch to head in feet, or .433 for most purposes. In order to make this equation of practical application, a term representing the head lost in overcoming friction, h_2, must be added on the right-hand side of the equation. This formula properly modified to the effect of frictional resistance, is the basis of all empirical formulas

for the flow of water.

The Venturi Meter is especially applicable to the measurement of water in pipes flowing under pressure. The formula for discharge is

$$Q = \frac{C\ n\ D_b^2\ Da^2 \sqrt{2gh}}{4\left(D_a^4 - D_b^4\right)^{1/2}}$$

By referring to figure 20, the symbols will be readily understood. For meters with a given ratio of throat and inlet diameter the formula may be simplified.

Let the ratio of $D_a/D_b = R$ and

Let

$$K = \frac{n\ R^2}{4}\left[\frac{2g}{R^4-1}\right]^{\frac{1}{2}}$$

Then $Q = C\ K\ D_b^2\sqrt{H}$ cubic feet per sec.

Values of R =	3.0	2.5	2.0
Values of K =	6.338	6.381	6.505

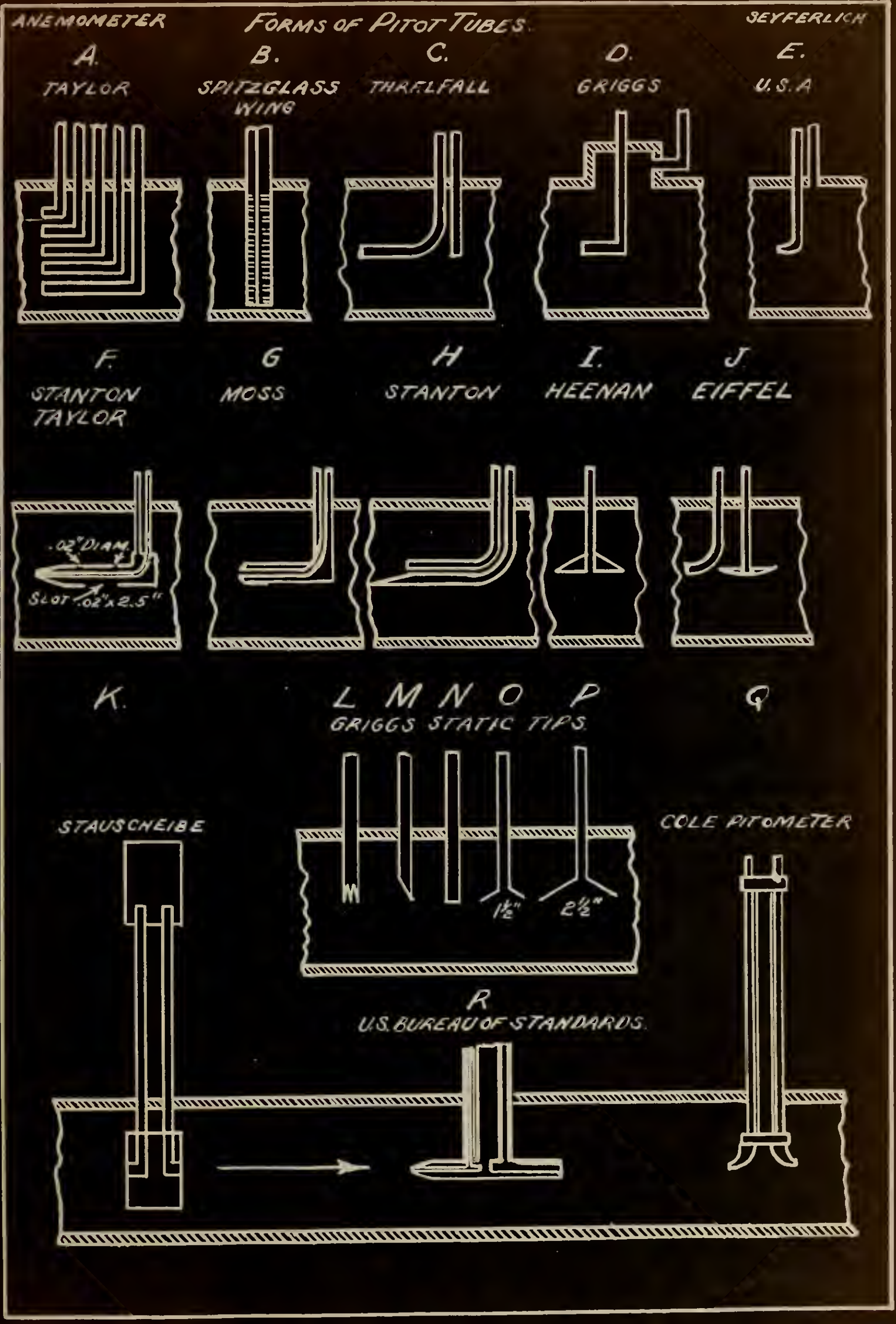
The values of C varies with the velocity at the throat, the ratio R and the actual dimensions of the meter. As the Venturi meters are ordinarily constructed, the coefficient C is usually between .97 and 1.03. These meters may be rated backward and a coefficient of correction found to apply to the menometer reading. The total loss of head through

the meter tube is relatively unimportant compared with other types of commercial meters and is so small that the insertion of the meter in mains of a water supply is rarely objectionable and the use of this appliance is growing constantly. It may be used particularly well in high-pressure power plants where a continuous reading may be obtained by the recording apparatus; also to measure boiler feed and for measuring liquids heavier and lighter than water. Experience has shown that with the register, continuous measurements have been made with an error not exceeding 3 per cent.

The Cole Pitometer, as illustrated in figure Q by the use of the differential gauge, registers the difference in pressure on the two orifices, one pointed directly against the current and the other in the exactly opposite direction. This difference in pressure is not a measure of the velocity head directly, but is greater than the velocity head. For these instruments the coefficient (K) of correction has been found to be nearly a constant, and equal to .84. The formula for velocity therefore becomes

PLATE No. 4.

FORMS OF PITOT TUBES.



$$V = K \left[2g(s'-1)\ d\right]^{\frac{1}{2}} \text{ ft. per sec.}$$

where s' = specific gravity of the heavier liquid,

d = the deflection in feet

V = velocity in feet per second

and K = the Pitometer coefficient.

The liquid used in the differential gauge is usually carbon-tetrachloride with either benzine, kerosene or gasoline used as regulating medium, and pitot red as coloring matter. The specific gravity may be thus controlled within certain limits, and is generally 1.25 or 1.50. For very accurate work the specific gravity should be determined for the temperature at which it is used.

The formula given above then reduces to:

$$V = \frac{.84 \quad 2gd}{4} = 3.368\ d^{\frac{1}{2}}, \text{ for } s' = 1.25$$

and

$$V = \frac{.84 \quad 2gd}{2} = 5.617\ d^{\frac{1}{2}}, \text{ for } s' = 1.50$$

where V represents the velocity in feet per second.

In order to determine the discharge, the cross-section of the pipe is divided into one or more known areas, as indicated in figure 21 the velocity for each area found and hence the mean velocity for the entire cross-section; the total discharge being simply

the product of the area and the mean velocity. For pipes the following table (Table No. 11) is useful, and the example given below illustrates how the discharge is calculated. The Pitometer is set so that the velocity is determined for the points indicated in figure 21. The pipe coefficient being first determined as in the example, it is subsequently necessary only to get a reading for the center of the pipe and apply the coefficient to the center velocity to obtain the mean velocity and hence the discharge by the formula:

$$Q = K\ C\ V_c\ A \text{ cubic feet per second.}$$

The principal use of the Pitometer is for measuring the flow in water mains where it has proved its great value in detecting leaks and waste, and in measuring the slips of pumping engines. It can be installed and operated for a relatively small expense, without interfering with the flow. For large penstocks, and in silt-bearing water it is not recommended. When used in old pipes allowance must be made for incrustations reducing the cross-sectional area and a traverse of several points through more than one

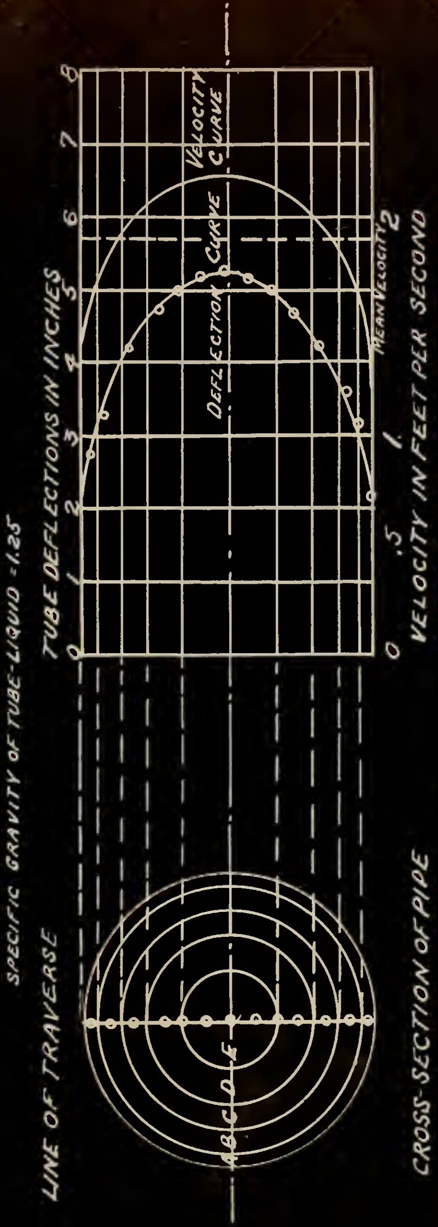

SPECIFIC GRAVITY OF TUBE-LIQUID = 1.25
TUBE DEFLECTIONS IN INCHES
0
1
2
3
4
5
6
7
8
VELOCITY CURVE
DEFLECTION CURVE
MEAN VELOCITY
0
.5
1.
2
VELOCITY IN FEET PER SECOND
LINE OF TRAVERSE
A
B
C
D
E
CROSS-SECTION OF PIPE

FIGURE 21.

diameter is preferable to the single observation and the use of the pipe coefficient.

The use of the Pitometer may best be illustrated by the following example given in conjunction with figure

Ring	Ring Area Square Feet	Ring Velocity Feet per Second	Ring Volumes of Flow Cubic Feet per Second
A	.502	1.57	.788
B	.873	1.87	1.632
C	.698	2.05	1.431
D	.720	2.18	1.570
E	.349	2.24	.781
TOTAL	3.142	Total Discharge	6.202

$$\text{Mean Velocity} = \frac{\text{Total Discharge}}{\text{Total Area}} = \frac{6.202}{3.142} = 1.97 \text{ ft./sec.}$$

$$\text{Pipe Coefficient} = \frac{\text{Mean Velocity}}{\text{Center Velocity}} = \frac{V}{V_c} = \frac{1.97}{2.24} = .879$$

Values of deflection and velocity for 24 inch supply main.

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TABLE NO. 11.

TRAVERSE TABLE FOR PITOMETER TESTING, SHOWING INNER DIAMETER OF EACH RING FOR ORDINARY SIZES OF MAINS IN INCHES; AND GIVING THE AREA OF EACH RING AND CENTRE CIRCLE IN SQUARE FEET.

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****

Diam. of pipe (in.)	Area of pipe (sq.ft.)		Ring A	Ring B	Ring C	Ring D	Centre circle E
48	12.566	Diam.	44	36	28	16	16
		Area	2.007	3.490	2.793	2.880	1.396
42	9.621	Diam.	38	32	24	14	14
		Area	1. 745	2.291	2.443	2.073	1.069
36	7.069	Diam.	34	28	20	10	10
		Area	0.764	2.029	2.094	1.637	0.545
30	4.909	Diam.	28	24	18	12	12
		Area	0.633	1.134	1.375	0.982	0.785
24	3.142	Diam.	22	18	14	8	8
		Area	0.502	0.873	0.698	0.720	0.349
20	2.182	Diam.	18	14	10	6	6
		Area	0.415	0.698	0.524	0.349	0.196
18	1.767	Diam/	17	15	11	7	7
		Area	0.191	0.349	0.567	0.393	0.267
16	1.396	Diam.	15	13	10	6	6
		Area	0.169	0.305	0.377	0.349	0.196
14	1.069	Diam.	13	11	9	6	6
		Area	0.147	0.262	0.218	0.246	0.196
12	0.785	Diam,	11	9	7	5	5
		Area	0.125	0.218	0.175	0.131	0.136
10	0.545	Diam.	9	8	6	4	4
		Area	0.103	0.093	0.153	0.109	0.087
8	0.349	Diam.	7	6	5	3	3
		Area	0.082	0.071	0.060	0.087	0.049
6	0.196	Diam.	5½	4½	3½	2	2
		Area	0.031	0.055	0.043	0.045	0.022
4	0.0873	Diam.	3½	2½	1½	-----	1½
		Area	0.0205	0.0327	0.0218	----	0.0123

NOTE: Diameter given in inches; area in square feet.

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PIEZOMETERS.

*****

Hiram F. Mills published in 1878 the results of some six thousand observations made with extraordinary accuracy to determine the proper form of piezometer orifice. With twenty-two openings varied in shape and direction and a range of velocities from .6 to 8.9 feet per second, he found that with an orifice whose edges are in the plane of the side of the channel and passage normal thereto, the piezometer column will stand neither above nor below the surface of the stream, but will indicate the true height of the water surface in an open channel or the pressure in a closed channel; but if the passage inclines either up stream or downstream, or the edges of the orifice project beyond the plane of the side, the true height of the surface or the true pressure will not be indicated.

****

THERMOELECTRICITY.

****

In a metallic circuit made up of two or more metals, a difference of potential (e. m. f.) exists at each junction of two unlike substances. However, from the law of the conservation of energy it follows that unless the circuit contain a source of energy, the resultant e. m. f. in the circuit must be zero, and no current flow can be established. This phenomenon also occurs in circuits made up of a single substance, whenever the substance is not physically and chemically homogeneous. The principal cases of thermal and contact action are:

1. The Seebeck Effect.
2. The Peltier Effect.
3. The Thomson Effect.
4. The Volta Effect of Contact Electrification.

1. THE SEEBECK EFFECT:

In 1821, it was discovered by Seebeck, of Berlin, that in a closed circuit consisting of two different metals, if a difference in temperature be maintained between the two junctions, there is an

electromotive force set up which caused the flow of an electric current. Thus, if one junction of a copper-iron circuit like that shown in figure 1, be kept in melting ice (0° Centigrade) and the other in boiling water (100° Centigrade) it will be found that a current passes from copper to iron at the heated junction and from iron to copper at the cold. The thermoelectromotive force developed in this case is about 1 microvolt or .001 of a volt. If, however, the temperature of the hot junction be raised gradually, the e. m. f. in the circuit slowly reaches a maximum, then decreases to zero, and finally is reversed. If the observations in e. m. f. and temperature be plotted, a curve like that of figure 2 will be obtained. In the case of the copper-iron circuit mentioned above, a parobola results, and is perfectly symmetrical about the vertical axis passing through its vertex, which corresponds to the value of temperature for maximum electromotive force. As indicated, this maximum is reached when the temperature of the hot junction is 260° C., with the cold junction at 0° C. Now if the cold junction be

kept at 100° C. instead of 0° C. the curve obtained in a similar manner will be exactly the same, except that the origin of co-ordinates will be moved from O to A, and electromotive forces will now be measured from the base line AB.

From the foregoing it becomes evident that the inclination or slope of the curve at any point, or in other words, the rate of change of thermal e. m. f. per degree change in temperature, depends only on the temperature of the junction which is being warmed or cooled, and not at all on the temperature of the other junction, provided its temperature is constant. This change of electromotive force per degree change of temperature of any junction, is known as the relative thermoelectric power of the substances involved.

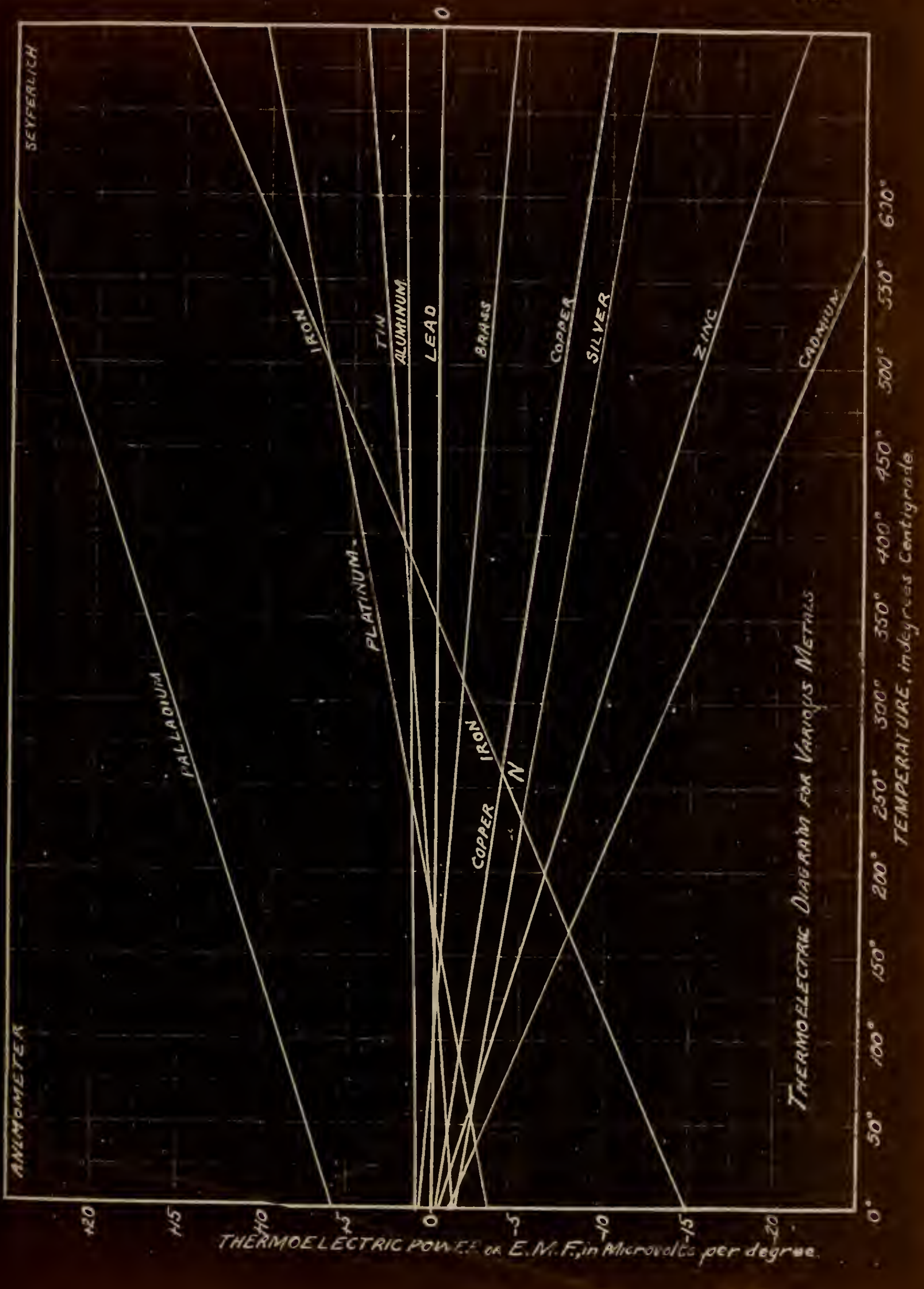
If the thermoelectric powers of iron and copper be plotted as ordinates, with the scale of temperatures as abscissa, a diagram like that of figure 4 results. The curve, as shown, is a straight line intersecting the axis at 260° C., for at that temperature the relative thermoelectric

power is zero, as explained above in connection with figure 2, where the maximum point is at 260° C. indicating that a small temperature change produces no change in thermal e. m. f. The value 260° C., therefore, is called the neutral temperature for those two metals.

In the thermoelectric diagram devised by Tait, the thermoelectric powers of the metals referred to lead (Pb.) are plotted as ordinates along a scale of temperatures as abscissae, lead being taken as a standard because the Thomson effect in it, is zero. The Thomson effect is explained in a later paragraph.

Such a thermoelectric diagram is shown in Curve Sheet No. 1, where it might be observed that within the limits of the diagram, the variations of the thermoelectric powers of the various metals with temperature changes, are represented by straight lines.

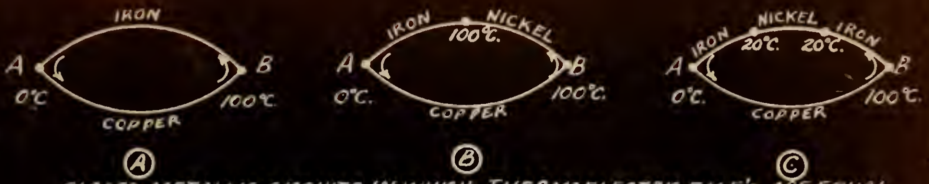
The electromotive force of a couple made up of any two metals is expressed by the area included between the lines of the two metals, and the ordinates of the temperatures of the junctions.


THERMOELECTRIC DIAGRAM FOR VARIOUS METALS
TEMPERATURE, in degrees Centigrade.
THERMOELECTRIC POWER or E.M.F., in Microvolts per degree.
ANTIMONY
SEYFERLICH
PALLADIUM
PLATINUM.
IRON
TIN
ALUMINUM.
LEAD
BRASS
COPPER
SILVER
ZINC
CADMIUM.
IRON
COPPER
N
0
+20
+15
+10
+5
0
-5
-10
-15
-20
0°
50°
100°
150°
200°
250°
300°
350°
400°
450°
500°
550°
600°

ANEMOMETER

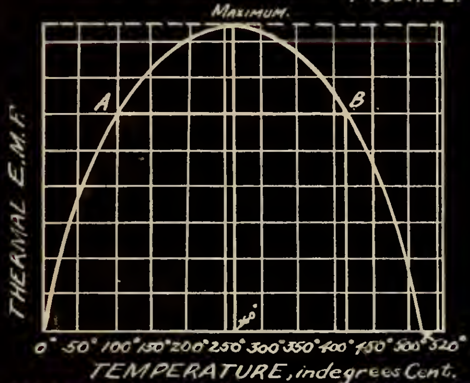
THERMOELECTRIC DIAGRAMS.

SEYFERLICH



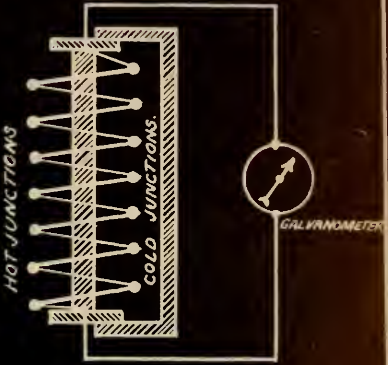
CLOSED METALLIC CIRCUITS IN WHICH THERMOELECTRIC E.M.F.'s ARE EQUAL.

FIGURE 1.



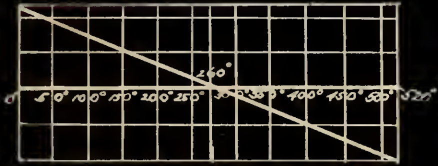
THERMOELECTRIC E.M.F.-TEMPERATURE CURVE FOR COPPER-IRON THERMOCOUPLE.

FIGURE 2.



THERMOPILE ARRANGEMENT OF THERMOCOUPLES.

FIGURE 3.



THERMOELECTRIC POWER DIAGRAM FOR IRON TO COPPER.

FIGURE 4.

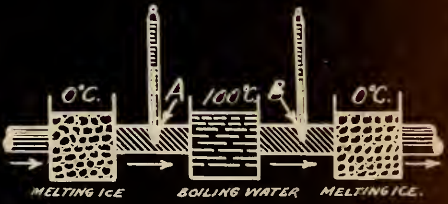
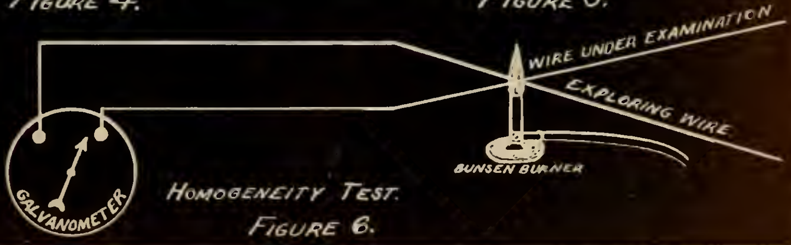


DIAGRAM SHOWING THOMSON EFFECT.

FIGURE 5.



HOMOGENEITY TEST.

FIGURE 6.

The diagram is so constructed that the direction of the resultant electromotive force is clockwise; that is, in the case of iron and copper between 0° and 100° Centigrade, the current will be from copper to iron at the hot junction.

2. PELTIER EFFECT:

When a current is passed across the junction between two different metals, an evolution or an absorption of heat takes place. This effect is entirely different than the evolution of heat due to the resistance of the junction (i^2r), and is reversible, heat being evolved when the current passes one way across the junction and absorbed when the current is reversed. There is a definite relation between the direction of the thermo-electric current and the sign of the Peltier effect. If a current be forced across a junction in the same direction as the thermo-electric current flows at the hot-junction, the junction will be cooled, or in other words, heat will be absorbed. Conversely, a current passing in the normal direction across the cold junction of a

thermo-electric circuit evolves heat. In general, then, a thermo-electric current absorbs heat at the hot junction and gives up heat at the cold junction. Therefore, a current produced in the same direction by external means must cool off the junction which serves as the "hot"junction and warm up the "cold" junction.

3. THOMSON EFFECT:

In a copper bar, heat is carried with the electric current when it flows from hot regions to cold ones; on the other hand, when the current flows from cold regions to hot ones, those hot parts of the bar are cooled. In the case of iron these effects are reversed. The conductor may be thought of as composed of a number of little elements of volume, at the junctions between which occur reversible heat effects, similar to Peltier effects at the junctions between different metals. The Thomson effect may be more readily understood by reference to figure 5, which shows the difference in temperature maintained between the two points A and B by means of

boiling water and melting ice placed about a metallic conductor. A flow of current results therefrom and the arrows in the figure indicate its direction. This effect, as mentioned above, is reversible.

4. VOLTA EFFECT OR CONTACT ELECTRIFICATION:

It can be shown experimentally that when any two unlike substances are placed in contact, there exists between them a difference of potential or voltage. Ordinarily, such an e. m. f. voltage is very small except in the case of electrolytes in contact with various metals. It may be stated that the value of this e. m. f. depends in any specific case, upon:

1. The substances in contact.
2. The character and condition of the contact surfaces.
3. The medium in which the contact occurs.
4. The conditions existing in that medium.

With reference to the Electron Theory, Contact Electrification may be explained as follows: Certain substances possess the property of readily

giving up electrons to other substances when the two different metals or substances are placed in contact. Thus, it has been demonstrated experimentally that zinc readily parts with electrons to copper, when the two metals are placed in contact. The consequence is that when two dissimilar substances are in contact, one acquires an excess of electrons and the other a deficit. Hence, one substance (the one which loses electrons) becomes positively electrified and the other (the one which gains electrons) becomes negatively electrified, and a difference of potential or a voltage difference is thereby established between them.

As an example, when a piece of zinc (in air) is placed in contact with a piece of copper, electrons pass from the zinc to the copper. The flow of electrons continues until the number of electrons, lost by the zinc and gained by the copper, is such that the voltage between the zinc and copper is just equal to the contact difference of potential, which always exists between zinc and copper of the same qualities and under the same conditions. It does not

appear to be definitely known just why some substances part readily with their electrons to others, or in other words, we do not know why the atoms of some materials hold their electrons more firmly than do those of other materials.

****

THE INTERPRETATION OF THERMOELECTRIC EFFECTS IN TERMS OF THE ELECTRON THEORY.

The free electrons inside of a conductor may be considered as moving about, exactly as the molecules of a gas. They thus exert a pressure corresponding to the pressure of a gas on its enclosure. This electronic pressure varies for different metals so that if two different metals are in contact there will be a greater pressure of electrons on one side of the junction than on the other. Suppose now, that we have a closed circuit consisting of two different metals with, therefore two junctions as in

figure 1 (a). Let the two junctions be at different temperatures. As in the case of gas pressure, the higher the temperature the greater the pressure. So by maintaining this temperature difference there will be a greater pressure driving the electrons from copper to iron at junction B, than from copper to iron at junction A. There will thus be a steady flow of electrons around the circuit, constituting the thermoelectric current.

Another explanation of thermoelectricity, which is generally accepted is as follows:

Assume two metallic strips or wires AB and BC, as shown in figure 6, soldered together at the point B. With the ends A and C connected to the terminals of a galvanometer G by means of copper conductors, heat is applied to the junction B, and hence the temperature of point B is raised above that of points A and C. There will then be a flow of current through the galvanometer and a deflection of the pointer. This is commonly explained by saying that at the junction B, heat energy is transformed into electrical energy, and this junction B is

regarded as the seat of an e. m. f. In the event the temperature of point B be maintained lower than that of points A and C, the current will flow in the opposite direction. In the following table some of the more commonly used metals are so arranged that when any two of them are chosen for such a circuit, current flows across the heated junction from any given metal, to one below it in the list.

Bismuth
Platinum
Copper
Lead
Silver
Antimony.

It should be noted that the presence of an intermediate metal or alloy at the junction, for example, solder, will not affect the value of the e. m. f. developed, because whatever effect is developed at one point of contact with the solder, is annulled at the other. Of the pure metals a thermo-

couple consisting of bismuth and antimony develops the greatest thermoelectro-motive force for a given difference in temperature. However, as explained later, certain alloys are frequently used for one or both members of a thermocouple. The purity and physical state of these materials is an important factor in securing uniformity of results. A thermocouple may be calibrated with a given galvanometer; that is, a curve may be plotted between temperatures and thermal e. m. f. as indicated in figures 2, etc.

The thermoelement or thermocouple then becomes a valuable and convenient device for measuring temperatures, especially for values of temperatures where other thermometers or other temperature indicating devices cannot be used. For the range, from liquid air temperature, -190° C. to 200° or 300° C., copper-advance or iron-advance thermocouples are often used. For high temperatures upward of 1700° C., a thermocouple of pure platinum and platinum-rhodium alloy is used. The various combinations are explained in detail in a later paragraph.

****

COMPLEX ALLOY COUPLES:

Several manufacturers have sought to produce base-metal couples which are free from some of the defects usually present in this type. The work done so far gives promise that this field of investigation is worthy of further development. Most of the effort has been on the modification of the iron and nickel elements by the addition of other metallic components such as tungsten, copper, chromium, cobalt, silicon, and aluminum. We may mention as examples, the Bristol, Tharing and Hoskins couples. The last mentioned of these, a robust nickel-chromium combination (Pure Ni, 90% Ni + 10% Cr.) develops an E. M. F. about four times that of the ordinary Platinum-Rhodium couples, and the E. M. F. temperature relation is nearly linear to 1400° Centigrade without any recalescence disturbances of sufficient magnitude to seriously affect the temperature readings in technical work, and after annealing this couple retains its readings sufficiently for many commercial uses, even when heated to over 1300° C. for short periods.

For high temperatures the Hoskins Company

now use principally the couple nickel-aluminum (2% Aluminum) against nickel-chromium (10% Chromium). For low temperatures a couple consisting of nickel-copper (65% Cu) against nickel-chromium (10% Cr.). The nickel-aluminum alloy is generally known as Alumel, while the nickel-chromium alloy is called Cromel. The temperature e. m. f. curve for a couple made up of these materials is shown in curve sheet No. 2. The copper-nickel alloy is likewise called Copel and when used against Cromel at low temperatures produces a temperature-e.m.f. curve as shown on the same curve sheet. The chief characteristics of the materials used in the Hoskins couple are given in the accompanying table.

A difficulty met with in the manufacture of complex alloy couples, is the reproducibility, or more properly, the degree of reproducibility of the same E. M. F. temperature relation from one couple to another. The identity of behavior is, however, highly desirable in cheap commercial couples which are frequently replaced, as it obviates the

necessity of recalibration or adjustment of the galvanometer scale for each couple.

****

TABLE NO. 12.

HOSKINS' THERMOCOUPLE CALIBRATIONS - COLD JUNCTION AT 25° C.

Positive Element	Negative Element	E. M. F. in MILLIVOLTS					
		100°C.	232°C.	419°C.	657°C.	800°C.	1065°C.
Nickel	90% Nickel + 10% Chromium	3.21	9.34	16.88	26.00	31.50	41.80
98% Ni + 2% Al	"	----	9.35	17.60	28.10	34.53	46.20
96-2/3% Ni + 3-1/3% Al	"	----	8.75	17.20	28.25	35.00	47.20
95% Ni + 5% Al	"	----	8.25	16.67	-----	-----	47.00
Cobalt	"	3.09	9.93	20.90	33.18	-----	45.58
65% Cu + 35% Ni	"	4.39	13.15	27.27	44.66	-----	75.40
Copper	"	1.48	4.15	7.73	11.27	-----	13.57

****

TABLE NO. 13.

ELECTRICAL RESISTANCE OF THERMOCOUPLE ELEMENTS.

Element	Resistance per foot .4 mm. wire at 25° C.	Specific Resistance at 25° C.	Temp. Coefficient per degree C.
Nickel......................	.26 ohm	10.34	.00415
96-2/3% Ni + 3-1/3% Al	.63	25.00	.00274
Cobalt......................	.356	14.15	------
65% Cu + 35% Ni	.99	39.3	------
Copper	.043	1.75	.00388
90% Ni + 10% Cr	1.76	70.0	.00051

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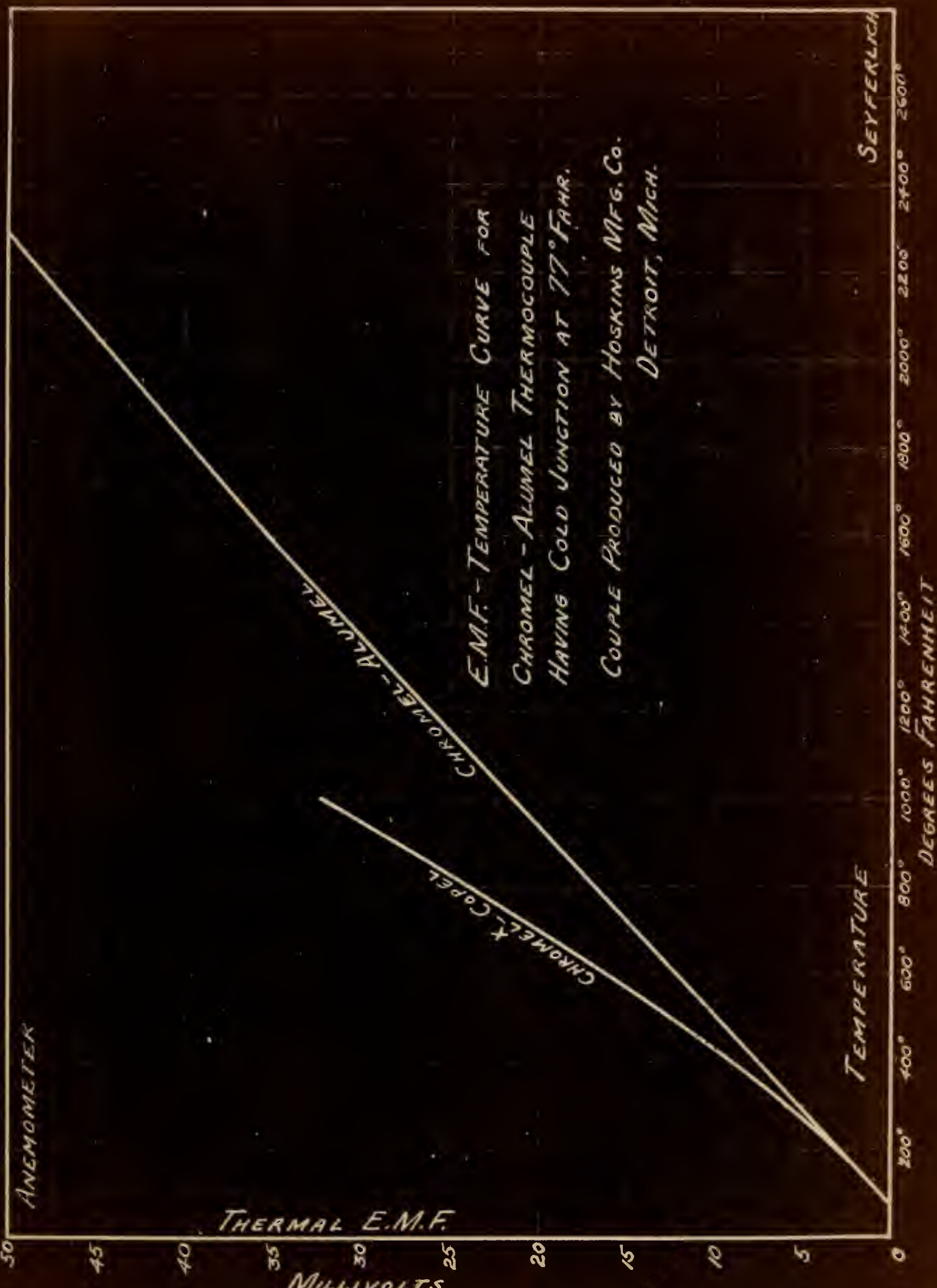
E.M.F.-TEMPERATURE CURVE FOR
CHROMEL-ALUMEL THERMOCOUPLE
HAVING COLD JUNCTION AT 77° FAHR.
COUPLE PRODUCED BY HOSKINS MFG. CO.
DETROIT, MICH.
CHROMEL-ALUMEL
CHROMEL-COPEL
ANEMOMETER
THERMAL E.M.F.
MILLIVOLTS
0
5
10
15
20
25
30
35
40
45
50
TEMPERATURE
DEGREES FAHRENHEIT
200°
400°
600°
800°
1000°
1200°
1400°
1600°
1800°
2000°
2200°
2400°
2600°
SEYFERLICH

THE LeCHATELIER PYROMETER.

In measuring temperatures between 300° and 1600° C., thermocouples consisting of a wire of rhodium alloy of platinum, joined to a wire of pure platinum, have been found to be most appropriate. The most common and widely used of this type consists of a wire of 10% rhodium alloy with platinum, joined to one of pure platinum, and is known as the LeChatelier pyrometer. For a thermojunction of this type the relation existing between the electromotive force (E) and the temperature of the hot junction (t), in the interval of temperatures from 300° to 1200° C., is quite accurately given by the equation,

$$E = a + bt + ct^2 \tag{1}$$

when the cold junctions are at 0° C. When this equation is extrapolated to higher temperatures than 1200° C., it gives lower than the correct value of temperatures. As an example, the melting point of platinum is found to be 1710° C. by this equation, instead of 1750° C. or higher, as given by recent work.

The Holman equation expresses the relation between E and t in the form

$$E = mt^n$$

(2) $$\log E = n \log t + \log m$$

and has been found to be sufficiently accurate for nearly all purposes. Results obtained by the use of this equation agree with those obtained by the use of equation (1) within approximately 2° C. in the range of temperatures from 300° to 1200° C. When extrapolated above 1200° C., this equation (2) gives values of temperatures more exactly than does equation (1). For high precision over very great temperature ranges the use of more complicated formulas becomes necessary.

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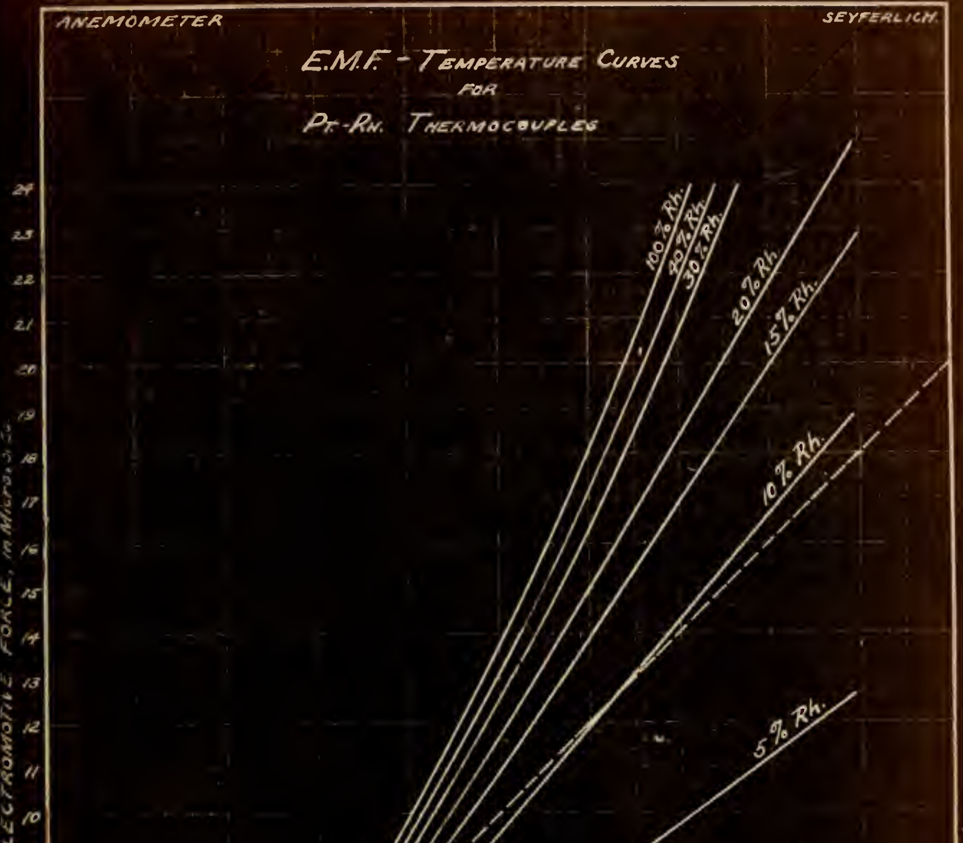

ANEMOMETER
SEYFERLICH.
E.M.F. - TEMPERATURE CURVES
FOR
PT.-RH. THERMOCOUPLES
100% Rh.
40% Rh.
30% Rh.
20% Rh.
15% Rh.
10% Rh.
5% Rh.
1% Rh.
ELECTROMOTIVE FORCE, in Microvolts
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
100°
200°
300°
400°
500°
600°
700°
800°
900°
1000°
1100°
1200°
1300°
1400°
1500°
1600°
1700°
1755°
TEMPERATURE, in degrees Centigrade

COLD JUNCTION:

As previously stated, the cold junction is the joint where the free ends of the two metals of which the thermocouple is composed, are connected to the leads running to the meter. Since the reading of the meter is proportional to the difference in temperature between the hot and cold junctions, the temperature of the cold junction is an important consideration. To obtain accurate meter readings, the cold junction must either be kept at a constant temperature or means must be provided for compensating for changes in temperature.

To maintain a constant temperature, one method employed is to pack the cold junction in ice, a thermos bottle containing the ice, being used for portable sets and some similar heat-containing device for permanent installations. The ice pack will last for about 24 hours, and it keeps the cold junction at a constant temperature of 0° Centigrade.

Another method of maintaining

constant temperature is to install the cold junction in a pipe buried in the ground. This does not bring the cold junction to the zero point, but inasmuch as the temperature is constant, once it has been determined, the scale of the meter may be calibrated for this temperature. Compensating lead wires which have the same characteristics as the thermocouple wires connect the thermocouple wires to the buried cold junction, and copper lead-wires are run from this point to the meter.

Without some means for keeping the cold junction at constant temperature, the variation of the readings from the correct values may be as large as from 60° to 120° Fahrenheit in temperature measurements. Still another method is to house the cold junction in a box in which the temperature is kept constant by means of a thermostatic control. One type of box consists of a case with glass front, containing two low wattage electric lamp bulbs, a thermostat, a thermometer and a terminal block to accomodate the required number of thermocouples.

The temperature of the interior is kept constant within a few degrees by alternately lighting and extinguishing the electric lamps, the operation being controlled by the thermostat. Another method to take care of the cold junction is to use a correction thermometer (water jacket terminal head, etc.).

ZERO CONDITION DEFINED:

The zero condition of a thermocouple is when both the "hot" and "cold" junctions are at the same temperature of melting ice, that is 0° Centigrade. If under these conditions the thermocouple in question be connected to the terminals of an indicating instrument, the pointer of that instrument should remain at Zero.

If, however, the entire combination is heated to a higher temperature, a marked deviation from the zero point usually takes place.

METHOD OF MEASUREMENT.

Instruments of three different types are used for measuring thermocouple e. m. f's: (1) Those operating upon the ordinary galvanometer

principle in which case the usual form of millivoltmeter may be used for direct measurement; (2) those operating on the potentiometer principle; and (3) those operating on a combination of these first two principles. For temperature measurements the first two have been made automatically recording.

(1.) DIRECT READING GAOVANOMETERS:

When a galvanometer is used for measuring the electromotive force of a thermocouple directly, it usually operates on the D'Arsonval principle, having a moving coil mounted between the poles of a permanent magnet. The galvanometer is connected in series with the thermocouple. The thermoelectric currents generated are of small magnitude, so that all connections should be made with great care in order to obviate errors which may be caused by undue resistance. This is especially true with low resistance galvanometers. They must be used exclusively with the particular leads and thermocouples whose combined resistance is provided for in the calibration of the instruments. Even

varying depths of immersion of these thermocouples is apt to introduce considerable error. A galvanometer with high internal resistance is not subject to such difficulties, because the resistance of the meter is so great in proportion to that of the leads that small variations of lead resistance do not affect the meter reading perceptibly. In commercial low resistance galvanometers the internal resistance rarely exceeds one ohm per millivolt deflection, while the high resistance galvanometers seldom run under 20 ohms per millivolt deflection. Low resistance pyrometers, however, are often used, as they meet the requirements for shop practice in certain industries with sufficient accuracy, and owing to the larger current handled the instrument can be made more rugged.

A galvanometer can be calibrated to read directly values of temperature, since the thermoelectric power generated is proportional to the heat at the thermojunction. The e. m. f.- temperature curve ordinarily approximates a parabola.

(2.) POTENTIOMETER-TYPE INSTRUMENTS:

A more precise method of measuring thermoelectric e. m. f.'s is by the use of the potentiometer principle, the indications in this method being independent of the thermocouple resistance. The fundamental principle of this method is illustrated in figure 23 A constant current from battery B, flows through the slide wire a b c. One wire of the couple T is connected to the movable contact b, and the other wire in series with a sensitive galvanometer, is connected to a. The sliding contact b is moved until the galvanometer reads zero, showing that no current is flowing through the thermocouple circuit; the true electromotive force of the couple is then equal to the potential drop across ab. As mentioned above, the current flowing through ab is maintained at a constant value. The potential drop across ab will therefore be proportional to the resistance of ab. The slide wire abc can be calibrated to read directly in millivolts or temperatures. In the latter case the section ab shows directly the temperatures of the hot

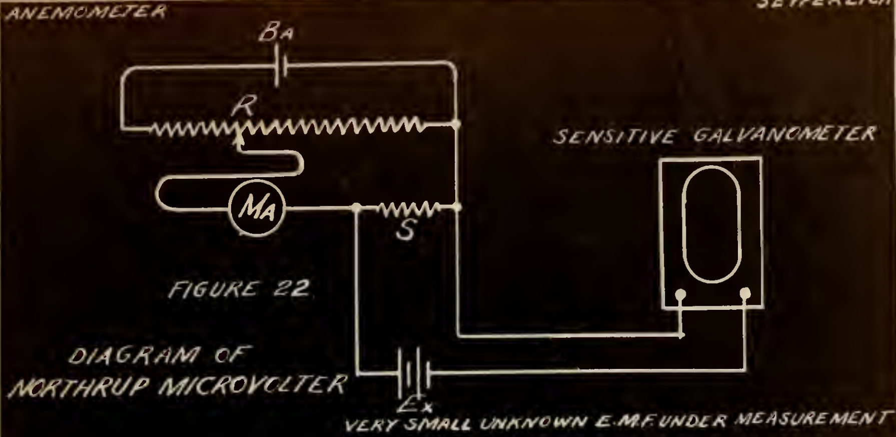


FIGURE 22.

DIAGRAM OF NORTHRUP MICROVOLTER

DIAGRAM ILLUSTRATING SIMPLE POTENTIOMETER PRINCIPLE FOR MEASURING THERMAL E.M.F.'S

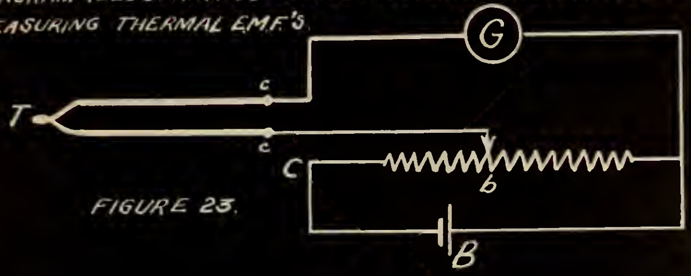


FIGURE 23.

DIAGRAMS ILLUSTRATING PRINCIPLE OF THE PYROVOLTER

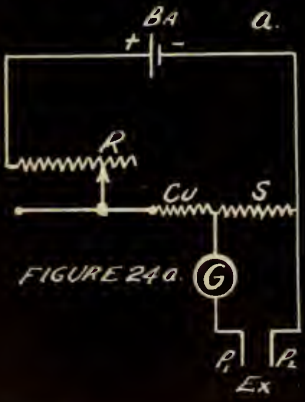


FIGURE 24a.

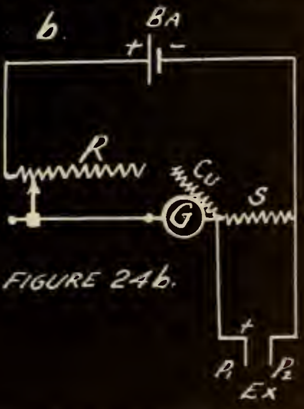
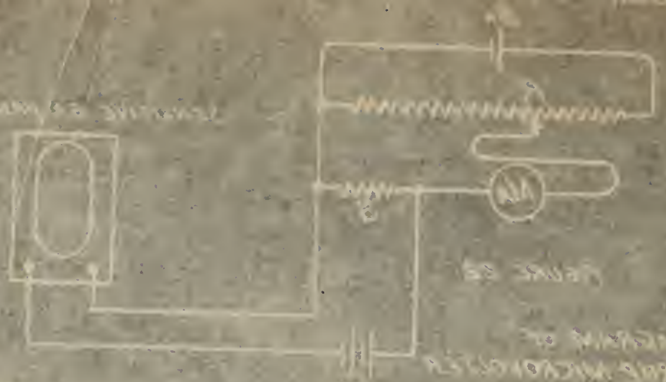
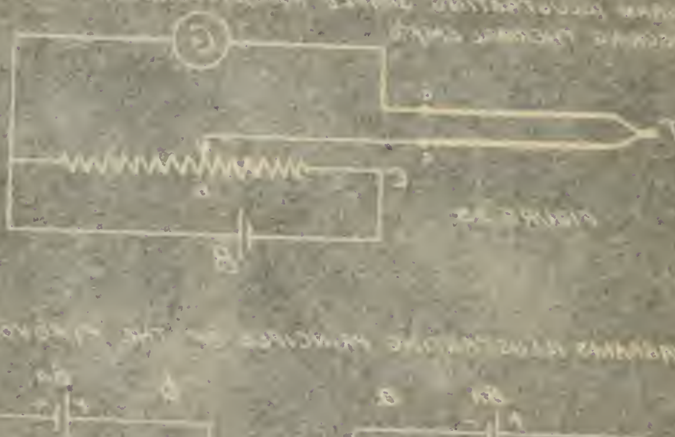
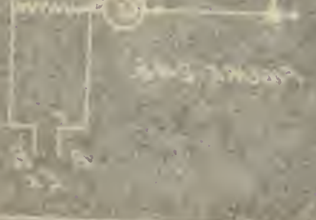
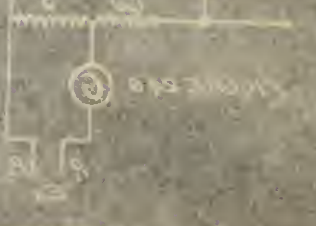


FIGURE 24b.









body. (A wiring diagram of the potentiometer type instrument is shown in figure 23.)

(3.) SEMI-POTENTIOMETER-TYPE INSTRUMENTS:

These instruments combine the principles of operation of the galvanometer and potentiometer type instruments above described. Referring to figure 24 (a), the dry cell B sends a current through the variable resistance R and the fixed resistances C and S. The resistance C is equal in value to the resistance of the galvanometer G. The couple T is connected in series with the moving coil of the galvanometer, across the resistance S. The resistance R is adjusted until the galvanometer reads zero. The thermocouple and the resistance C are then thrown out of the circuit, and C is replaced by the galvanometer G, having an equivalent resistance as shown in figure 24 (b). The galvanometer pointer is now deflected by an amount proportional to the current flowing throughout, which in turn is proportional to the potential drop across S, and since this potential difference was made equal to the voltage of the couple by the initial setting for zero

deflection, the galvanometer indicates directly the time value of the e. m. f. developed by the couple.

A potentiometer used as described above, requires a manual adjustment of a dial or slide wire every time an observation is made. This objectionable feature is practically eliminated in the deflection-type potentiometer, which may be so constructed as to embody the accuracy of the ordinary potentiometer and the convenience of the galvanometer, which reads the value of temperatures directly.

DEFLECTION-TYPE POTENTIOMETER:

In the deflection potentiometer, part of the electromotive force of the couple is balanced against the potential drop over a resistance, through which a current is flowing, while the remainder is indicated by the deflection of a galvanometer connected in series with the couple. The resistance is set to balance the approximate e. m. f. developed by the couple, and this setting, read in millivolts, combined with the galvanometer reading,

gives the true voltage of the couple. In many industrial processes the temperature of the couple will vary only slightly during several hours, so that a new setting is infrequently required. The method for obtaining the voltage of the couple is thus nearly as simple as when an ordinary galvanometer is used to measure the thermocouple voltage directly.

ADJUSTMENT OF COLD JUNCTION TEMPERATURE:

The various methods of controlling and maintaining constant, the temperature of the cold junction have been given above. It was shown that unless the temperature of the cold junction were kept constant at the melting point of ice, 0° Centigrade, it becomes necessary to make allowances for the difference between the cold junction temperature and the zero point. In the galvanometer type meters the adjustment for the cold junction temperatures can be applied directly by mechanically setting the pointer of the galvanometer back on the scale, an amount equal to the actual temperature reading of the cold junction. To accomplish this same adjustment,

the whole scale may be moved so that the zero point of the scale comes at the point where the cold junction temperature read on the scale before it was moved. These methods of correcting are accurate, but, of course, require new settings whenever the temperature of the cold junction is altered. Indicators of the potentiometer-type frequently have a moveable slide on the scale of the meter or on an auxiliary dial. When this slide is set to the temperature of the cold junction it compensates for the cold junction temperature. This method also requires new settings whenever the temperature of the cold junction is altered. With large and permanent installations the applying of corrections for the temperature of the cold junction by any of the above methods is frequently troublesome, since the temperature may vary considerably within a few hours. There are several methods for avoiding this difficulty. One method is to have the head of the couple fitted with a water jacket, maintained at practically constant temperature. Correction for cold junction temperatures can also be made by using compensating leads, special shunt circuits and the like.

THERMOELECTRIC PROPERTIES OF TANTALUM AND TUNGSTEN.

****

Tantalum is obtainable in fine wires, is pliable, and does not oxidize readily at ordinary temperatures, and hence suggests itself as a substitute for iron (or steel) in connection with constantan wire in thermopiles. The following observations on the thermoelectric behavior of tungsten and tantalum may be of interest.

The tantalum wire employed was 25 cms. long and .048 mms. in diameter. It was taken from an unused incandescent lamp. The resistance was .85 ohm per cm., which amounted to approximately .9 of that of a sample of steel wire. The ends of the tantalum wire were wound tightly around copper wires, about .1 mm. in diameter and the junctions were soldered. The copper wires were joined to a potentiometer, by means of a mercury reversing switch, and the comparisons made against a standard cell. Observations were also made on copper-constantan,

and on iron-constantan couples, of wires .0513 mm. in diameter. The temperature was varied from 10° to 100° C., and an attempt was made to eliminate the lag of the mercury thermometer. Observations were also made at the temperatures of liquid air, and of solid carbon dioxide. The results are shown in the form of curves, figure 1 on the following page. It should be noted that the black dots indicate the observations on the tentalum-copper couple drawn to scale.

As a matter of contrast, the thermoelectric power of a tantalum-copper couple found by Pearson in an account given in the Electrician 63, p. 594, 1909, is only about one-tenth of this value. Since no check measurements were made on known elements, the discrepancy may be due to an error in recording results. Pearson's observations were made by joining the couple directly with a galvanometer.

As given in the curves on the following page, the observations at 10°, 24°, 32° and 47° respectively, belong to the first series. The observations at 17°, 50°, and higher temperatures

were made on a new couple and show no marked variation from the preceding. The plain circles indicate observations on the copper-constantan couple , the ordinates being drawn to one-tenth the scale of the tantalum couple, and graduated in microvolts.

The results show that throughout the range investigated, the thermoelectric power of tantalum against copper, is about 4.1 microvolts per degree, which is one-tenth that of the copper-constantan couple. The direction of the current is the same as in the copper-constantan couple.

The tungsten wire used in the following experiments was taken from a large "series" lamp. It was about 11 cms. long and .26 mm. in diameter. To the ends were wound copper wires of .1 mm. diameter, and the joints were covered with solder. Tungsten being very brittle in this state, the sample was accidently broken before observations were completed, so that the observations at 231° and 269° (the freezing point of tin and bismuth, respectively) were made with a length of wire less than 6 cms. long, the

copper wires being fused to the tungsten. It was found that this did not affect the results.

The e. m. f. temperature curve of tungsten is given in figure 2, on the following page, and is rather unusual in that its inversion temperature occurs at about 40° C. In this respect its behavior is somewhat similar to that of copper-zinc, the inversion temperature of which comes to 30° C. Another combination, which has its inversion temperature near 0°, is iron cadinum, and its inversion temperature comes at 170°.

From the appearance of the accompanying curve for the copper-tungsten couple, it is inferred that the thermoelectric curve is not a true parabola, as was also observed by Dewar and Fleming on numerous other metals. (See Dewar and Fleming in Phil. Mag. 40, p. 95, 1895). For temperatures below -100° C. the thermoelectric power of tungsten against copper is about 3.5 to 4 microvolts per degree, — 200° C. the thermoelectric power is about 4.5 microvolts per degree, so that tungsten, like tantalum shows no apparent advantage in thermocouple work.

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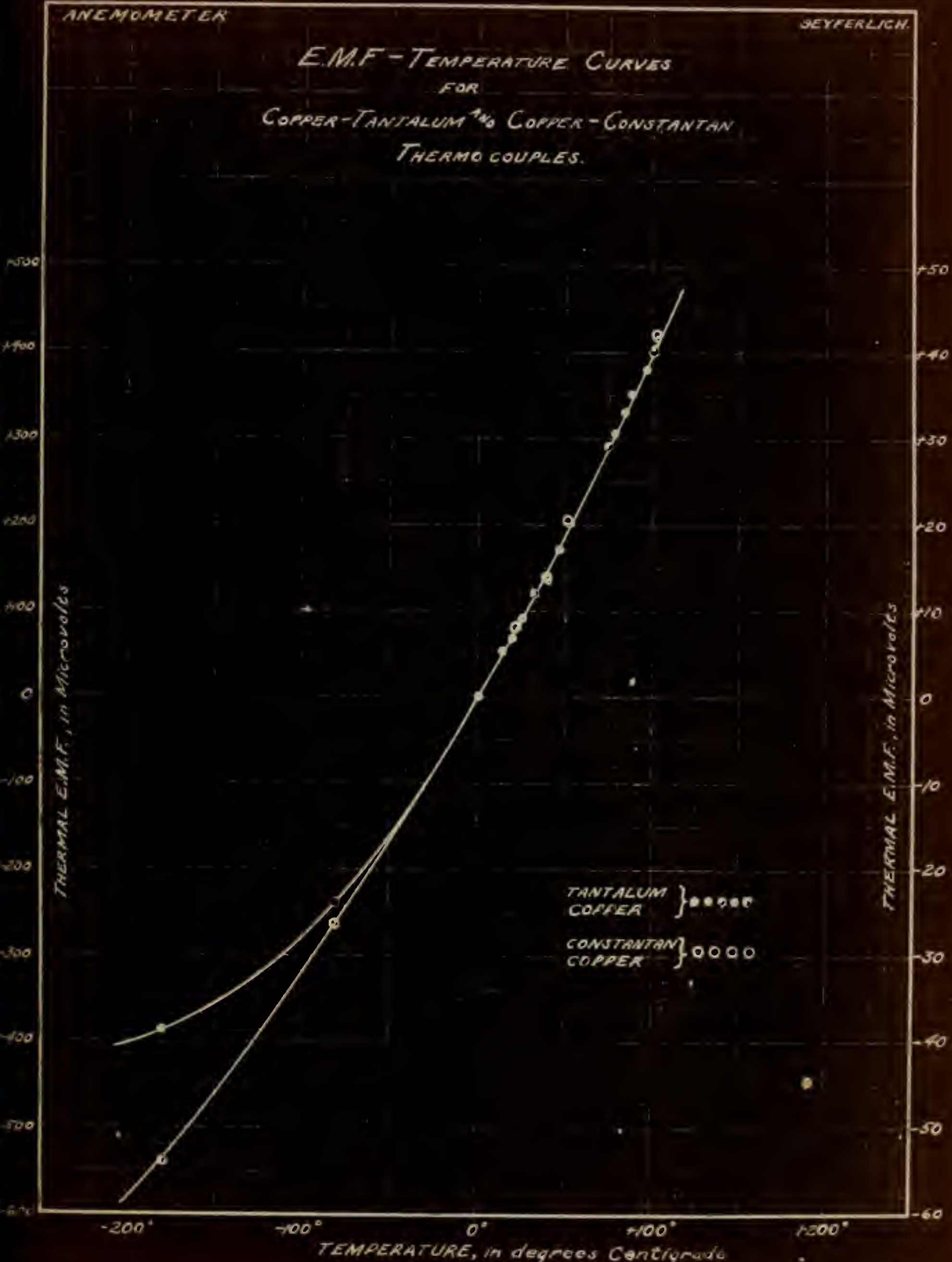

ANEMOMETER
SEYFERLICH.
E.M.F - TEMPERATURE CURVES
FOR
COPPER-TANTALUM AND COPPER-CONSTANTAN
THERMO COUPLES.
+500
+400
+300
+200
+100
0
-100
-200
-300
-400
-500
-600
THERMAL E.M.F., in Microvolts
+50
+40
+30
+20
+10
0
-10
-20
-30
-40
-50
-60
THERMAL E.M.F., in Microvolts
TANTALUM COPPER } ● ● ● ● ●
CONSTANTAN COPPER } ○ ○ ○ ○
-200°
-100°
0°
+100°
+200°
TEMPERATURE, in degrees Centigrade

MEASUREMENT OF VERY SMALL CURRENTS BY MEANS OF THERMOELEMENTS WITH SPECIAL REFERENCE TO RADIO CIRCUITS.

There are various methods used for the measurement of currents of a few milliamperes or less. Such measurements may be made by the use of thermal ammeters of various types, and in general, are free from some of the difficulties experienced in the measurement of larger currents, principally because conductors of very small cross sections may be used the resistance of which does not vary with the frequency of the current under measurement. The various types of thermal ammeters employ the following principles: Crossed-Wire Thermal-elements, Self-Heated Thermoelement, Thermo-galvanometer Volometer. Instruments operating on these various principles are described below.

Prior to the war thermoelectric couples had been employed for measuring low values of alternating current. These couples were almost exclusively of German manufacture and not extremely accurate nor sensitive. There have since been

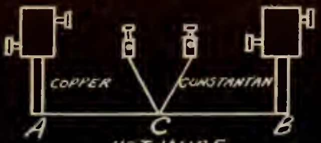
developed and marketed thermoelectric couples of American manufacture, which are superior in every way and are now available for the accurate measurement of alternating currents of any frequency. Their sensitivity is such that a current of one milliampere will produce a deflection of 3 millivolts in a. d. c. voltmeter.

The heat developed in a hot wire may be indicated by means of a thermocouple, placed very near or in contact with the hot-wire. The thermoelectromotive force developed may then be measured by a suitable type of direct current instrument. The indications in this type of instrument depend upon the temperature at one point only on the hot-wire, instead of upon the heating effect throughout the whole wire, as in the case of the expansion type of ammeter. As indicated in figure 25 in the simple type, AB, is the fine wire which carries the high frequency current under inspection. The copper-constantan or other thermocouple used is either hard soldered or welded to AB at the point of contact C, and the elements are connected to binding

ANEMOMETER

SEYFERLICH.

THERMO ELECTRIC AMMETERS.



HOT-WIRE
FIGURE 25

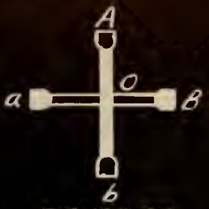


FIGURE 26.

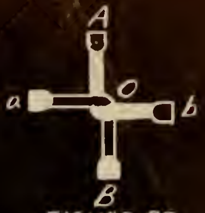
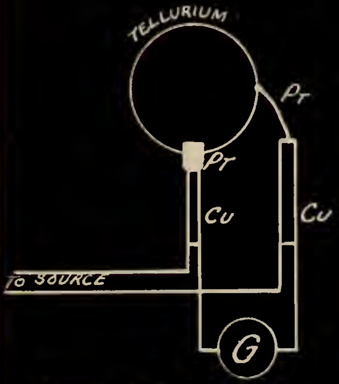


FIGURE 27.



PLATINUM-TELLURIUM
SELF-HEATED THERMOCOUPLE
FIGURE 28.

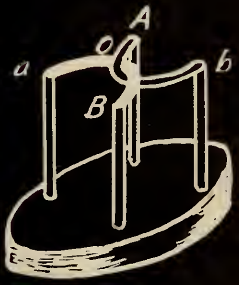
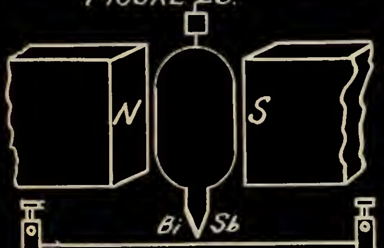


FIGURE 29.



DUDDELL THERMOGALVANOMETER
FIGURE 30.

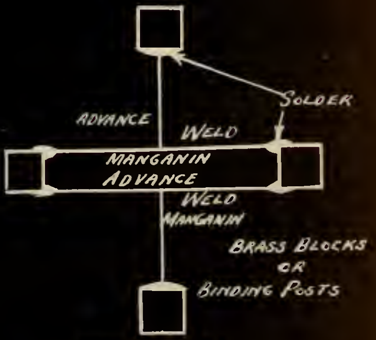


FIGURE 31.
SO-CALLED "BRIDGE-ARRANGEMENT"
OF THERMOCOUPLES IN SERIES.

posts and thence to a galvanometer. Such an instrument may be easily constructed for laboratory use for measuring current values up to 2 amperes. Commercial instruments are made by combining the hot wire, thermocouple, and a pointer-type micro ammeter into a single instrument.

The thermocouple instrument has a permanent-magnet moving-coil system which is connected to a thermocouple or a bridge arrangement of thermocouples. It appears probable that the operating advantages of the thermocouple instrument will cause it to eventually supersede the hot-wire instrument. For some purposes, however, the hot-wire instrument has an advantage over the bridge form of thermocouple ammeter in that the former indicates correctly the value of a direct current regardless of its direction, while the thermocouple ammeter may even deflect below zero for one direction of the current.

CROSSED-WIRE THERMOELEMENT:

Sensitive thermoelements are easily made

and are extensively used in measuring small high-frequency currents. They consist essentially of two wires of different metals in contact, one or both of them being of very small diameter. The heat due to the I^2R in the fine wire raises the temperature of the junction, thus giving rise to a thermoelectromotive force which is indicated by a direct current galvanometer. A simple type of the crossed-wire thermoelement is made up of two fine wires of different metals and which are crossed in either of the ways indicated in figures 26 and 27.

The high frequency current to be measured is lead in through the heavy copper wires A and B and the indicating galvanometer is connected at the points a and b. The sensitivity of the thermoelement depends upon the diameter, thermoelectric properties, and resistivity of the wires, and their length if very short, on the intimacy of contact of the two wires, and on the air-pressure. Permanent contact of the two wires may best be obtained by fusing or welding, or else by soldering

the junction. The use of a minute particle of solder does not appreciably reduce the sensitivity of the couple. If the junction is not soldered or fused, some thermoelements are occasionally found to have an unusually high degree of sensitivity, which is probably due to particularly poor contact between the two metals; the high resistance of the poor contact causes the production of heat just at the junction and the amount of which is large relatively to the heat produced in the wires. In some thermoelements this poor contact remains sufficiently constant, so that the thermoelement may be relied upon, but in others it does not.

The materials which have been ordinarily used for these thermoelements are constantan and steel, and constantan and manganan. Using wires about .02 mm. in diameter and 4. mm. long a constantan-steel thermoelement has a resistance of about 1 ohm and gives about 40 microvolts for 15 milliamperes high frequency current. Using a galvanometer with a sensitivity of 2.5 mm. per

microvolt, it follows that a deflection of 100 mm. is produced by a high frequency current of 15 milliamperes. The thermal electromotive force is very closely proportional to the square of the high frequency current. Thus, the typical thermoelement just mentioned gives a deflection of only 1 mm. for 1.5 milliamperes current. These thermoelements have practically no thermal lag because of their being made of such fine wire, and it therefore is more appropriate to use a very quick-acting galvanometer with them.

Smaller currents can be measured by the use of thermoelements made of wires of a still smaller diameter. The resistance, the I^2R loss, and therefore, the temperature rise, would be higher for any given value of current. In the case of most radio circuits, however, high resistance is objectionable and should be preferably avoided, so that thermoelements which are of high resistance and sensitivity have little application.

Another method of increasing sensitivity at the expense of increasing the resistance of the

circuit, is to connect the thermoelement, not directly into the circuit, but to the low voltage side of a current transformer in the circuit. This has the advantage that the galvanometer is not metallically connected to the main circuit and hence its capacity is less likely to cause leakage of high frequency current from the main circuit. The exact limitations of this method are not known; but it seems likely that the calibration will change with frequency and with the resistance and inductance connected to the transformer.

The above figures on sensitivity are for thermoelements in air at ordinary atmospheric pressure. No variation of sensitivity with the ordinary barometeric pressures has been observed , but the sensitivity may be greatly increased by placing the thermoelement in a vacuum. It has been found that an air pressure of about .01 mm. of mercury or lower is necessary to gain much in sensitivity, but that in such low vacua, the sensitivity of thermoelements of polished metal wires

may be increased as much as 25 times. The removal of the air eliminates the cooling of the thermoelement by convection; and a given value of current therefore causes a higher temperature rise. The temperature of a hot body in a vacuum is limited only by radiation of heat from its surface, thus the temperature of a polished metal surface, which is a poor radiator, rises higher than that of a dull metal surface, which is a good radiator.

SELF-HEATED THERMOELEMENT:

In the type of thermoelement described in the preceding section, the high-frequency current does not pass through the wires of the thermocouple itself. The thermocouple wires Oa and Ob, indicated in figure 28, touch the wires OA and OB which carry the high-frequency current, at one point only. There is no particular reason why the thermocouple wires themselves may not carry the high-frequency current to be measured so that the junction may undergo a rise in temperature. A simple thermocouple so used may be called a self-heated thermo-

couple. By using this type of couple, L. W. Austin of the Bureau of Standards, found it possible to utilize tellurium as one of the metals of a thermoelement, and one with which a high degree of sensitivity was obtained. Thus, a couple of tellurium and platinum develops an e. m. f. about 25 times that of a similar couple of constantan and platinum at the same temperature.

These thermoelements may be made as follows: Two copper wires are placed side by side about 3 mm. apart, and imbedded in unsulating material with their ends protruding, as indicated in figure 28. To the end of one of these copper wires is soldered about 5 mm. of platinum of constantan wire about .02 mm. in diameter, To the end of the second copper wire is soldered a short length of platinum wire, .8 mm. in diameter, on the opposite end of which a bead of tellurium had previously been attached, while the platinum was heated to a white-heat. White-hot platinum wire when inserted in tellurium forms practically a resistance-free contact. The end of the fine wire of platinum is next

allowed to rest against the tellurium and the two are welded together electrically by means of a small induction coil with a high resistance in series with the secondary. The contact will be less fragile if the welding is done in an oxygen-free atmosphere. The resistance of a thermo-element prepared in this way may be anywhere from 5 to 50 ohms, depending upon the conditions of welding and the resistance of the fine wire, the lower resistance being somewhat more difficult to obtain. The thermoelement is next inclosed in a test tube, and if it is to be handled roughly, this tube may be inclosed in a larger one with cotton or felt between the two. These thermoelements have been found to remain constant over considerable periods, but some have been found to lose their sensitiveness after a year or two. A 32 ohm thermoelement was found to give a deflection of 1 mm. on a very sensitive galvanometer, when a high frequency current of 120 micro-amperes was measured. Such theremoelements give very satisfactory results when used in connection with portable microammeters of the pointer type.

It should be remembered that thermoelements of the self-heated type cannot, of course, be used on direct current since the galvanometer forms a shunt on the heating wire. At high frequencies, however, the current is kept out of the galvanometer because its impedance is so much greater than that of the short lengths of thermocouple wires which it shunts. It should be noted that the heating current passes through both junctions of the thermocouple, (hot and cold junctions) but that the temperature of only one rises appreciably, because a fine wire of high resistance is used at one junction only. Large cross section at the other junction prevents a large heat production, and hence temperature rise.

****

SELECTION OF RESISTANCE MATERIAL.

****

The prime requisite of the resistance material used for resistance elements and winding coils, is permanence. In addition, its temperature coefficient should be small, its thermal e. m. f. when opposed to copper, low, and to obtain compactness, its resistivity should be high. Alloys rather than pure metals are used for they have smaller temperature coefficients and higher resistivities. To settle the all-important question of permanence, prolonged investigation is of course necessary. Up to the present time, the alloy which has most commended itself is that known as manganin. Other alloys have been used for certain kinds of work, but manganin has been under critical examination longer than the others and its properties are more definitely known.

Edward Weston discovered in 1889, that alloys of copper and nickel, containing some manganese, have small temperature coefficients and high resistivities. Investigation has shown that the

particular alloy known as manganin is when properly employed, sufficiently permanent for resistance coils and resistance standards.

The possible effects of a rise in temperature on a resistance coil or wire, are:

1. If the rise in temperature is small there will be a temporary change in resistance; that is, one which disappears when the normal temperature condition is regained.
2. If the rise in temperature is great, there will be a permanent alteration of the reistance.
3. At a still higher temperature the insulation will be impaired.

It is evident that the ability of a resistance coil to dissipate the heat due to the passage of the current is most important, and as the precisions which may be obtained with various methods of measurement are proportional to the currents employed, it is advisable, when selecting a resistance box for general use, to chose one having coils of a

high watt-capacity.

In any case, where a resistance coil or wire is to be used, the safe working current is that which will heat the coil or wire to a temperature just below that at which a permanent alteration or "set," in the resistance will take place. Thus, a coil adjusted to maintain this degree of liability, must be more carefully treated than one certified to .05 per cent., which is a degree of adjustment frequently used in the better class of bridges and resistance boxes for general use.

In order to determine what materials are the most suitable for our purpose, the list of alloys which may be used as resistance wires under various conditions are given with their most important and characteristic advantages and disadvantages in their usage.

****

RESISTANCE METALS.

COMPOSITION AND CHARACTERISTICS OF VARIOUS ALLOYS.

****

(1) ADVANCE: (See Constantan.)

Advance is a copper-nickel alloy containing no zinc. It has a uniform composition, and its resistance is approximately constant under nearly all conditions of service. It is highly recommended for use in apparatus in which the wire is to be subjected to repeated heating and cooling.

(2) CALIDO:

Calido is an alloy consisting of a high percentage of nickel-chromium and a small percentage of iron. Its melting point is about 1530° C. or 2780° Fahrenheit. Calido is particularly adaptable where there are considerable variations in voltage. Under such conditions it undergoes no internal changes due to high temperature action, at temperatures up to 1000° C. and hence does not deteriorate within this range. Besides being

used in heating devices, it is used to considerable extent in the construction of rheostats, resistance coils, etc.

(3) CLIMAX:

Climax is a high resistance nickel steel alloy and its greatest field of application is in the construction of rheostats. It is one of the cheapest of all resistance metallic combinations.

(4) COMET:

Electrical Alloy Comet is a nickel-chromium steel alloy and is the result of extensive research work for an alloy that would withstand oxidation and corrosion with more success than straight nickel-steel resistors. This has been accomplished by the addition of chromium in proper proportions. Comet is therefore adapted to all resistance work at moderately high temperatures where high resistance and durability are prime requisites. These qualities make it well fitted for use in electric room-

heaters and other black-heat operating devices. When used with IDEAL, COMET presents a thermocouple capable of developing a comparatively high thermal e. m. f., and much greater durability than the Iron-Ideal or Copper-Ideal couples often used, because Comet is much more durable than iron or copper, and does not oxidize nearly as readily when heated.

(5) CONSTANTAN:

Constantan and the other materials such as Advance, Ia Ia, Ideal, 30% German Silver, etc., having substantially the same properties, are alloys of approximately 60 per cent copper and 40 per cent nickel.

Owing to its uniform composition and its practically unvarying resistance qualities, it is particularly useful where the apparatus into which it is placed, is to be subjected to comparatively wide temperature changes. It is especially applicable for use in rheostats, thermoelements, and other

measuring instruments.

(6) EXCELLO:

Excello is an alloy which is used in many heating devices operated by electricity.

(7) GERMAN SILVER:

German Silver is an alloy of copper, nickel and zinc. There are various grades of german-silver, the grade depending upon the percentage of nickel present. The most widely used combination has 18 per cent nickel.

The resistance of any particular grade depends upon the degree of annealing and in this connection the harder the grade wire has a slightly higher resistance than the soft.

For many years, this alloy was about the only resistance alloy obtainable, but it is now being generally displaced by materials of the same specific resistance or resistance qualities, but, which possess other superior qualities.

(8) IA-IA:

This alloy is to be recommended for use in instruments and electrical devices where a low temperature coefficient of resistance is desirable.

(9) IDEAL:

Ideal is an alloy of nickel and copper, and contains no zinc or tin. It has been developed for use in electrical measuring instruments, resistance coils, precision rheostats, and other similar apparatus and devices requiring absolute accuracy and permanency. It is particularly valuable in apparatus in which the winding is required to carry a current sufficiently large to cause heating. Its very low temperature coefficient, which is given as .000005 per degree C., or .000003 per degree F., keeps the resistance of the winding constant even for a marked rise of temperature, a highly desirable and important characteristic.

Ideal has a further important field

of application in thermocouple pyrometry. When used as one element of a thermocouple, in conjunction with COMET as the other, it produces a high value of thermal e. m. f., and the combination forms a couple which is considerably more desirable than Iron-Ideal or Copper-Ideal often used. According to the manufacturer, no matter what the other element may be, Ideal is one element of practically all base metal couples manufactured on a commercial scale.

Ideal contains no volatile metals such as zinc, and,therefore, even if it be strongly overheated, is not injured and does not become brittle, which presents a great advantage over German Silver.

(10) KARMA:

A highly developed pure nickel-chromium resistance wire. It is claimed by the manufacturers that the durability of this wire under high continuous temperatures, combined with its high resistance accuracy, is a revelation to

the electric heating industry. By adopting Karma for elements in quality high temperature apparatus , the life of the element is said to be greatly increased and burn-outs due to overloads, which the usual Nickel-Chromium wire cannot withstand, are thus eliminated. It has a specific resistance of 620 ohms per circular milfoot or 103 microhms per cubic centimeter at 20^{0} Centigrade, and its temperature resistance curve between 0^{0} and 1000^{0} C. approximates a straight line. The percentage increase in resistance with rise in temperature between 0^{0} and 1000^{0} C. is about 10 per cent, or an average of 1 per cent per 100 degrees temperature rise.

(11) KROMORE:

The applications of Kromore are very much the same as those of Nichrome and Nichrome II with the exception that Nichromes are more suitable for low temperature heating while Kromore is better for open elements and radiant heats. Kromore is a straight nickel-chromium

alloy and works up to about 2100° F. It has a specific resistance of from 580 to 610 ohms per circular milfoot, and a temperature coefficient of — .000134 per degree F.

(12) KRUPP METAL:

Krupp Metal is an alloy of nickel steel and is a special grade adapted for resistors and resistance applications.

(13) LUCERO:

Lucero was originally developed as a direct result of the increasing demand for an inexpensive resistor to replace German Silver. The result of this research work was the production of Lucero, a nickel-copper alloy that is more permanent than German Silver and has greatly superior mechanical and electrical properties.

Lucero can be used to greater advantage than German Silver because of the trouble presented by the zinc content of the latter. Zinc volatilizes with relatively low

temperature rises and this results in the break-down of any alloy containing it.

Lucero, however, is non-corrosive, durable, and will neither break down structurally nor become brittle under repeated heating and cooling. It has a much higher melting point than German Silver and is more desirable in the construction of rheostats, car-heaters, etc. because of its permanency.

(14) MANGANIN:

The composition of Manganin is more commonly given as 84 per cent copper, 12 per cent manganese and 4 per cent nickel. Its resistivity at 20° C. is about 44.5 microhms per cm. and its thermoelectro-motive force when opposed to copper is only .000002 volts per degree Centigrade. To insure permanence it is advisable to protect this material with a well-dried coat of shellac.

The curious effect of a rise of temperature on a manganin resistance coil is shown in the curve of figure Z on the follow-

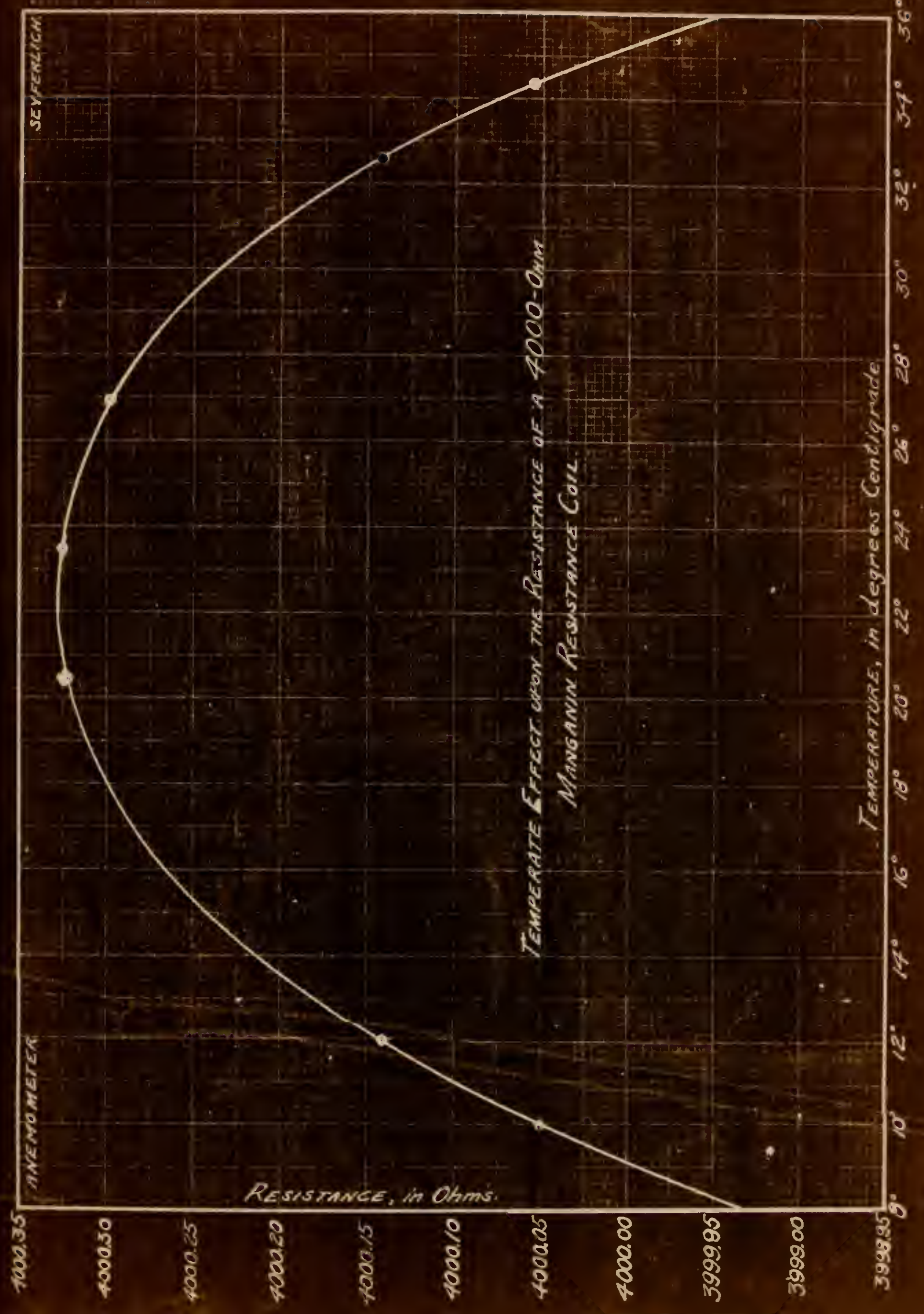
ing page. The point at which the temperature coefficient changes sign and other properties of this wire vary with different samples of the material.

It will be noted that the temperature coefficient is very small, the average value between 15° C. and 20° C. being only .0005 per cent. for engineering work, consequently, temperature corrections may be neglected. In work of the highest precision (a few parts in 100,000) temperature corrections must be made, in which case the coefficient applying to the particular coil in hand must be employed.

Investigation has shown that Manganin is, when properly employed, sufficiently permanent for resistance coils and resistance standards.

(15) NICKEL:

Nickel is a refined metal of exceptional purity and uniformity of quality. It has a high malleability and will withstand use



Temperate Effect upon the Resistance of a 4000-Ohm Manganin Resistance Coil

at continuously high temperatures. Due to its high temperature coefficient, nickel is very efficient for use in resistance thermometers, and owing to its non-corrosive qualities, it may be employed for rheostats and resistance appliances where acid fumes are to be encountered. Nickel, therefore, is found in the manufacture of hospital, laboratory, chemical and surgical instruments and utensils because of the ease with which it may be sterilized and its great resistance to corrosion.

(16) NO. 193 ALLOY:

This alloy serves successfully in low temperature air-heaters, and makes good elevator controllers and rheostat resistances. The upper limit is 1200° F. It gives satisfaction in fine gauges up to 30. It is a nickel-chromium alloy with much the same characteristics as Climax, but is more resistant to oxidation and rusting, and gives longer service. It has a specific electrical

resistance of 525 ohms per circular milfoot at 24° C., and a temperature coefficient of resistance of .0004 per degree Fahrenheit.

(17) FERRO-NICKEL:

On account of its low specific resistance, Ferro-Nickel has a high current carrying capacity. However, this alloy will rust if circumstances are not appropriate, and hence it can be used only where it will not be subjected to moisture.

(18) MAGNO NICKEL:

This alloy is of nickel-manganese and owes its development to the demand for a satisfactory substitute for platinum and other expensive metals, used in the manufacture of spark-plug electrodes, ignition points, ignition tubes and contact points. It has a high melting point and may be subjected to repeated heating and cooling without exhibiting the slightest tendency to disintegration. It can also be machined readily and made into special shapes. It may be made in various

degrees of hardness or softness,and many spring tempers. It will not corrode and may be welded or soldered readily.

(19) **MONEL METAL:**

This metal ordinarily contains approximately three parts of nickel to one of copper, or about 71 per cent Nickel, 27 per cent Copper and 2 per cent Iron. Its resistance has been found to vary somewhat in different lots, according to temper and proportioning of the constituents. The variation, however, will be found no greater than that of 18 per cent German Silver.

In the manufacture of Electrical Alloy Grade "A" Monel Metal the nickel content is given as 67 per cent. This combination is claimed to be as strong as steel and to possess exceptionally corrosion-resisting properties. It bears a marked resemblance to pure nickel in color and takes a brilliant polish.

Varying atmospheric conditions such as may be encountered in the Tropics, along the seaboards

heated resistance elements and appliances where extreme conditions are to be encountered.

(21) NICHROME II:

Nichrome II is an alloy which is strongly resistant to oxidation. It has been especially developed for use in carbon combustion furnaces, and other types of laboratory furnaces where the more extreme temperatures are to be met.

(22) PHENIX:

Electrical Alloy Phenix is a nickel-steel material eminently appropriate for resistance work at comparatively low temperatures. It is relatively inexpensive but when used in the proper class of service for which it has been developed, will be found to withstand corrosion and oxidation successfully. Its most widely known application is in resistors of controllers for electric elevators, cranes, automobiles, locomotives, as well as arc lamps, rheostats and other places where heavy duty resistance is

or in mines, acid fumes, live steam and other fluids and gases have no perceptible effect on its structure or physical characteristics. It is highly recommended in preference to phosphor-bronze, nickel steel or similar metals which tend to rust and disintegrate. Grade "A" Monel Metal may be machined readily; is tough and yet ductile; has a high tensile and torsional strength; resists electrolysis, acid fumes, and acid action to a marked degree and can be soldered, brazed and welded readily.

(20) NICHROME:

Nichrome is an alloy which is far superior to nickel in its ability to withstand high temperatures. It is practically non-corrosive and has an extremely high melting point, given as 2822° Fahrenheit or 1340° Centigrade. It is used very extensively in the making of protection tubes for base-metal thermocouples, owing to its non-corrosive properties. Nichrome is especially recommended for use in electrically

desirable. It may be soldered readily with any standard flux.

(23) RAYO:

Rayo is an alloy of nickel and chromium of such composition that it is particularly well adapted to use at very high temperatures. It has been used successfully in the windings of electric furnaces, stoves, ovens, and high temperature devices in general. Rayo can be used continuously at high temperatures, up to and including 1100° C., without scaling, or even becoming oxidized or brittle under extraordinary conditions generally favorable to oxidation and corrosion. This characteristic, as well as the fact that its resistance is fifty-seven times that of copper, accounts for its wide application in electric ranges and ovens.

(24) SUPERIOR:

Superior is an alloy which is used to a great extent in rheostats, arc lamps and other resistance appliances.

(25) THERLO:

This alloy is composed of copper,

manganese and aluminum and like manganin possesses the desirable property of developing a very low thermo-electromotive force against copper. Compared with manganin, this alloy gives a higher specific resistance, does not oxidize as readily, and is more stable in its electrical and mechanical behavior. This alloy is especially suitable for shunts. Its temperature coefficient is given as —.0000031 per 1° Fehrenheit.

(26) YANKEE SILVER:

This is a comparatively new alloy with most of the qualities of "18 per cent German Silver." It will stand repeated heating and cooling and very often gives satisfactory service where German Silver fails.

****

TABLE NO. 14.

PROPERTIES OF "THERLO" RESISTANCE WIRE.

****

Specific electrical resistance 46.7 michrom centimeters or 280 ohms per circular mil foot at 75° F. (24° C.)

Temperature coefficient of electrical resistivity at 20° C. practically nil. Best available present data — 0.0000031 per degree Fahrenheit (20 to 50° C.)

Coefficient of Linear Expansion — 0.000194 per degree Centigrade.

Thermal E. M. F. against Copper — 0.0015 millivolts per degree Centigrade over temperature range of 0 to 100° C.

Specific Gravity 8.15. Weight per cubic inch .29 lb.

NO. B. & S.	DIAMETER IN INCHES	AREA IN CIRCULAR MILS. C.M. = D^2	RESISTANCE PER 1000 FT. AT 75° F.
30	.010	100.0	2,800.
31	.0089	79.2	3,535.
32	.008	64.0	4,375.
33	.0071	50.4	5,555.
34	.0063	39.7	7,052.
35	.0056	31.4	8,917.
36	.005	25.0	11,200.
37	.0045	20.2	13,366.
38	.004	16.0	17,500.
39	.0035	12.2	22,950.
40	.003	9.0	31,111.

****

TABLE NO. 15.

PROPERTIES OF "ADVANCE" RESISTANCE WIRE

****

Specific electrical resistance 294 ohms per circular mil foot at 75° F. (24° C.)

Temperature coefficient of electrical resistivity at 20° C. practically nil.

Thermal E. M. F. against Copper about 4.25 to 4.4 millivolts between 0 and 100° C. or about 6.6 millivolts between 0 and 150° C.

Coefficient of Linear Expansion 0.0000144 per degree C.

Specific Gravity 8.9. Weight per cubic inch .32 lb.

NO. B. & S.	DIAMETER IN INCHES	AREA IN CIRCULAR MILS. $C.M. = D^2$	RESISTANCE PER 1000 FT. AT 75° F.
30	.010	100.0	2,940.
31	.0089	79.2	3,680.
32	.008	64.0	4,600.
33	.0071	50.4	5,830.
34	.0063	39.7	7,400.
35	.0056	31.4	9,360.
36	.005	25.0	11,760.
37	.0045	20.2	14,550.
38	.004	16.0	18,375.
39	.0035	12.2	24,100.
40	.003	9.0	32,660.

****

WORKING TABLE, STANDARD ANNEALED COPPER WIRE

American Wire Gauge (B. & S.)

Gauge No. B.&S.	Diameter in Mils	Cross-section Circular mils	Cross-section Square Inches	Ohms per 1000 ft. 25° C. (= 77° Fahr.	Ohms per 1000 ft. 65° C. (= 149° Fahr.
30	10.0	101.	0.0000789	105.	121.
31	8.9	79.7	0.0000626	133.	153.
32	8.0	63.2	0.0000496	167.	193.
33	7.1	50.1	0.0000394	211.	243.
34	6.3	39.8	0.0000312	266.	307.
35	5.6	31.5	0.0000248	335.	387.
36	5.0	25.0	0.0000196	423.	488.
37	4.5	19.8	0.0000156	533.	616.
38	4.0	15.7	0.0000123	673.	776.
39	3.5	12.5	0.0000098	848.	979.
40	3.1	9.9	0.0000078	1070.	1230.

****

TABLE NO. 17.

DIAMETER OF WIRE IN INCHES AND MILLIMETERS.

****

B. & S. GAUGE NUMBER	BROWN & SHARPE or AMERICAN WIRE GAUGE -	
	In.	Mm.
30	.01003	.2546
31	.008928	.2268
32	.007950	.2019
33	.007080	.1798
34	.006304	.1601
35	.005614	.1426
36	.005000	.1270
37	.004450	.1131
38	.003965	.1007
39	.003531	.0897
40	.003145	.0799

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[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]
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* * *

CURRENT CARRYING CAPACITY OF WIRES.

****

The carrying capacity of a wire under specified conditions is the current which under the conditions named, will raise the temperature of the wire a specified number of degrees. In order to define carrying capacity properly, it is, therefore, necessary to name the conditions under which the wire is tested, as straight horizontal, in open air, or spiralled and enclosed in a heat insulated space, etc., and to name the temperature rise for each size of wire under these conditions.

The tables of carrying capacity given throughout the work, unless otherwise specified, refer to wire stretched out horizontally, and with free access of air; but with no current of air striking the wire, except the convection currents caused by the heated wire itself.

It becomes obvious that countless figures for carrying capacity may be obtained by simply varying the conditions of testing.

It should, therefore, be understood that the tables given throughout the work, are not applicable to wires used under such conditions as in the winding of electric furnaces, the heating coils of immersion heaters, etc. The figures are not intended as a guide to the selection of the proper size of wire for use under any other conditions than the cooling of electrically heated wires by either free or forced convection air currents. For this reason only values for relatively fine sized wires ranging from No. 30 to No. 40 B. & S. gauge are given.

****

TABLE NO. 18.

AMPERES CARRYING CAPACITY OF "ADVANCE."

Wire Coiled in Air with Free Radiation. Rise in Temperature above 75° F. (24° C.)

CURRENT IN AMPERES.

B. & S. Gauge	F. 100° C. 56°	200° 111°	300° 166°	400° 222°	500° 277°	600° 333°	700° 388°	800° 444°	900° 500°	1000° 554°
30	1.0	1.2	1.5	1.8	2.1	2.5	2.8	3.1	3.3	3.6
31	.9	1.1	1.4	1.6	1.9	2.3	2.5	2.8	3.0	3.2
32	.8	1.0	1.2	1.4	1.7	2.0	2.25	2.5	2.6	2.9
33	.7	.9	1.1	1.2	1.5	1.8	2.0	2.2	2.3	2.5
34	.60	.80	.90	1.1	1.3	1.6	1.8	1.9	2.1	2.2
35	.55	.70	.85	1.00	1.20	1.45	1.60	1.75	1.85	2.05
36	.50	.60	.75	.90	1.05	1.25	1.40	1.55	1.65	1.80

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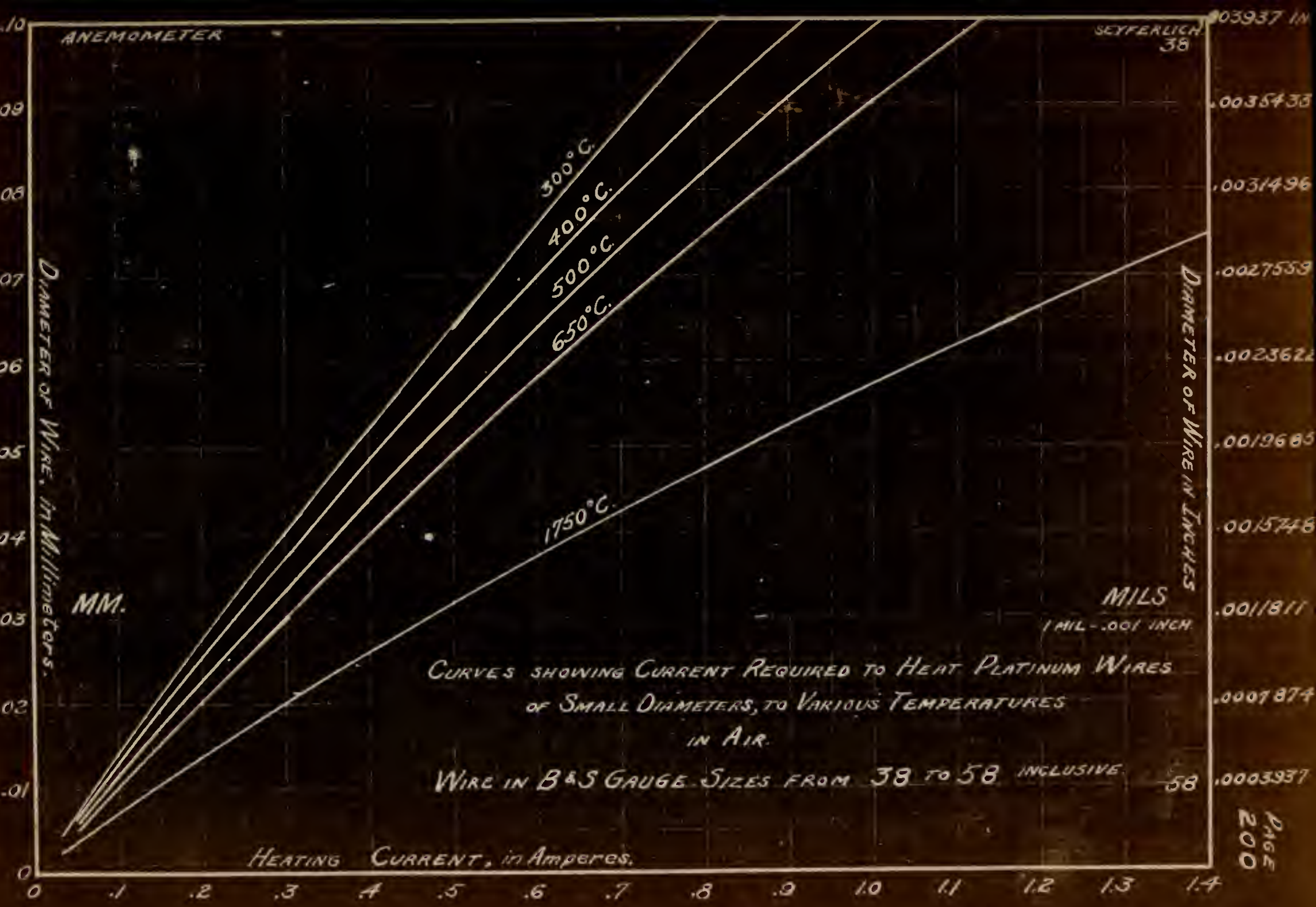
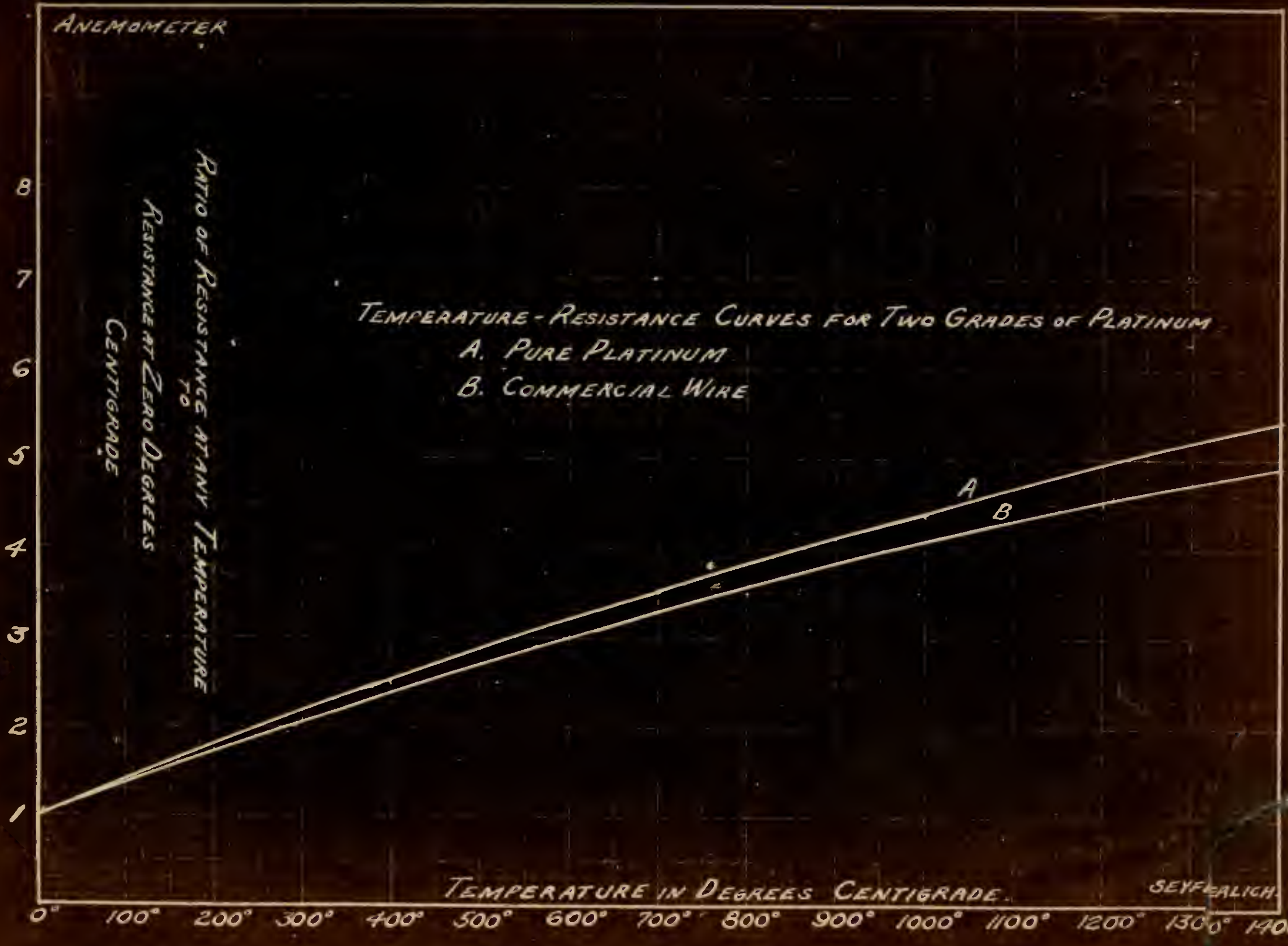


Curves showing Current Required to Heat Platinum Wires of Small Diameters, to Various Temperatures in Air.

Wire in B&S Gauge Sizes from 38 to 58 inclusive.


ANEMOMETER
TEMPERATURE - RESISTANCE CURVES FOR TWO GRADES OF PLATINUM
A. PURE PLATINUM
B. COMMERCIAL WIRE
RATIO OF RESISTANCE AT ANY TEMPERATURE TO RESISTANCE AT ZERO DEGREES CENTIGRADE
A
B
1
2
3
4
5
6
7
8
0°
100°
200°
300°
400°
500°
600°
700°
800°
900°
1000°
1100°
1200°
1300°
1400°
TEMPERATURE IN DEGREES CENTIGRADE.
SEYFEALICH

SCIENCE AND RESEARCH ACHIEVEMENTS.

The facilities for the manufacture of instruments necessary to give airplanes, pilots and observers their greatest usefulness were extremely limited at the outbreak of the war. The making of these instruments involved practically the formation of an industry new to this country. By June 1918, twenty types of instruments were in production and being supplied for installation in training, bombing, and fighting planes. The list included airspeed indicators, altimeters, compasses, safety belts, oxygen apparatus, radio sets and all other necessary adjuncts for the navigation of the air and for safety and comfort of the pilot.

The Aeronautic Instruments Section of the Science and Research Division of the Signal Corps, in addition to fulfilling the function specifically assigned to it of writing all the initial specifications for aeronautical instruments in use on planes, and in working continually with the instruments in production in order to detect imperfections and make suggestions for improvement, designed and developed

wholly within its organization, through the activity of its chief, Major C. E. Mendenhall, a new and improved Pitot-Venturi tube for use in determining of airplane air-speed. This instrument was actually put into production and thirty-seven thousand ordered.

Among the various activities of the Bureau of Standards for the Air service were Aerodynamic Investigations including the calibration of hundreds of Pitot tubes and Pitot-Venturi combinations for measuring the speed of the airplane. These investigations employed the use of the Bureau Wind Tunnel.

****

THE HOT-WIRE VACUUM GAUGE.

****

During the war the production of thermionic tubes in large quantities necessitated the development of very simple testing methods whereby the degree of vacuum obtained, could be continuously indicated to the operators of the vacuum pumps in the tube factory. In this way any defects in the operation of any "exhaust station" would be noted before an appreciable part of the product suffered from imperfect manufacture, and a uniform product would be insured. Two types of precise and direct reading gauges were developed for use under factory rather than research laboratory conditions; the Hot-Wire Gauge and the Inization Manometer.

One of these, the Hot-Wire Gauge or Manometer, is shown in the cut on this page, and consists of a platinum helix mounted in a suitable bulb, and permanently attached to the apparatus in which the pressure is to

be measured. One of these manometers formed part of the permanent equipment of each exhaust station. To observe the pressure the helix is made one arm of a Wheatstone Bridge and the pressure is obtained from a relation, previously determined by calibration, between the resistance of the helix and the corresponding pressure. The bridge circuit has a slide wire calibrated to read directly pressures below .1 mm. of mercury, each division representing .001 mm. The bridge may be set for a certain pressure and the galvanometer continuously indicates variations about this pressure.

****

THE THERMOELECTRIC STANDARD CELL.

****

Most engineers are familiar with the uses and limitations of standard calls of the Clark and Weston types. Those who have used either of these cells know that they will not function at freezing or boiling point temperatures, and are easily damaged if an appreciable current is drawn, as by accidental short circuiting.

The increasing use of potentiometers in commercial service, especially in connection with the measurements of temperature by means of thermocouples, makes it very desirable to secure a substitute for the standard cell usually required by these instruments. The serious shortage of standard cells caused by the war has emphasized this need. Furthermore, it is being recognized that it is poor economy to use a costly precision standard in a commercial potentiometer which reads to three significant figures at the most.

In order to eliminate the standard cell from the type of thermocouple potentiometer used in

measuring the temperature of electrical machines, it has become quite common practice to use a calibrated current measuring instrument for setting the current. A long-scale galvanometer, in connection with a suitable shunt, is used as a deflection instrument for setting the current in the potentiometer circuit. After setting the current, the same galvanometer is used as a null instrument for balancing the thermocouple e. m. f. against the potentiometer. The chief objection to this practice is the fact that it necessitates the use of a very high-grade galvanometer. A long-scale galvanometer, suitable for use as a deflection instrument, is necessarily much more costly and more delicate than a short-scale instrument of the same sensitivity. For this reason it is desirable to provide a means for setting the current which will not only eliminate the standard cell but will also remove the necessity for a high-grade deflection instrument.

Though the Hoxie Thermoelectric cell about to be described is not, strictly speaking, a primary standard or source of e. m. f., as is the

Clark or Weston cell, it is at least free from the above drawbacks. It may be more properly classed as a secondary standard, its value being determined by comparison with a primary standard. In fact, it is just as legitimate to call it a standard of current as of e. m. f., and perhaps a little more so, for the reason that it is simply a combination comprising a resistance, a thermo-junction and a heater wire or filament arranged in such a manner that it requires a current of a certain definite value in order for it to function properly. A standard value of e. m. f., however, may be obtained by taking the drop across a suitable resistance placed in the circuit.

To be more explicit, the Hoxie Thermoelectric Standard Cell in its present form consists of a glass bulb containing a thermo-junction T, a heating filament H. which is not in contact with the junction, the balancing resistance R and the drop resistance R_1. These are mounted in a case with binding post connections on the top.

If a battery and galvanometer are connected,

as shown in figure 32 , and the current adjusted to a critical value, the galvanometer will indicate a balance. The reason for this may be readily understood by referring to Curve No. 9. The curve a represents the drop of potential across the balancing resistance R as a function of the current through the heater H. The curve b shows variations of the thermal e. m. f. and is approximately proportional to the second power of the current through the heater, while the drop across the resistance R varies directly. The point of intersection C of these curves is that point at which the thermal e. m. f. developed by the couple equals the drop across the resistance R_1. In order to obtain a high value of thermal e. m. f. it is desirable to heat the filament to a high temperature in this type of cell. The maximum current that can be used without affecting the constancy of the cell, is that value which will bring the filament to a dull red heat when viewed in a dark room. Under actual operating conditions, the filament current is generally maintained somewhat below this value to prevent

THERMO-ELECTRIC STANDARD-CELL.

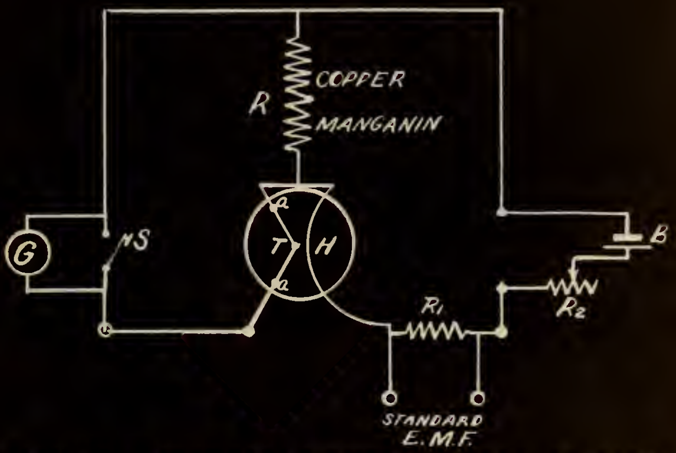


FIGURE 32 – DIAGRAM OF THERMO-CELL CIRCUIT

T = Hot Junction of Thermocouple.
H = Heating Filament
a = Cold Junctions of Thermocouple.
R = Balancing Resistance
R_1 = Drop Resistance
R_2 = Regulating Rheostat
S = Galvanometer Short-Circuiting Switch.
B = Battery
G = Galvanometer

damaging the cell due to an accidental increase.

In many of the tests with these cells a lead storage battery having a maximum variation in e. m. f. from 2.4 to .8 volts has been employed. By reducing the filament current to about 10 per cent below the reddening point the cell can be constructed so that 2.4 volts applied to its terminals will not damage the cell. The adjustment to the critical balancing current is then secured by means of a rheostat in the battery circuit.

TEMPERATURE COEFFICIENT:

Since the drop and balancing resistance are constructed of wire which has a negligible temperature coefficient, any change in the potential across the drop resistance must be due to a variation of the thermal e. m. f.

It is found that when the cell has been adjusted so that the current necessary for a balance is sufficient to bring the filament to a dull red heat, the cell has no measurable temperature coefficient. If adjusted to any smaller value of current a negative

coefficient results. This is due to the fact that up to a certain point, a rise in the surrounding temperature increases the thermal e. m. f. of the couple for a given difference in temperature between the cold and hot junctions. Apparently this critical point is reached when the filament attains a dull red heat.

The fundamental cause of the temperature coefficient of the cell is, as previously stated, the positive temperature coefficient of the thermal e. m. f. If a portion of the balancing resistance is constructed with the proper amount of some metal having a positive temperature coefficient, the increase in thermal e. m. f. is balanced by an increased drop across the balancing resistance, hence it becomes unnecessary to vary the filament current. The temperature coefficient of the cell has thus been compensated for.

In constructing a suitable form of cell for commercial work, considerable experimental work was necessary to determine the proper construction and arrangement of the various parts of the thermal cell.

The results of this work are given below.

HEATING FILAMENT AND COUPLE WIRES:

The heating filament and junction wires are kept under tension in order to maintain a constant position with respect to each other. The tension is produced by small spirals located at the base of the bulb. Even with this construction, it is probable that the relation between the heater and filament will vary, due to contraction and expansion of the metal springs. At a first approximation one would suppose that this separation would seriously effect the thermal e. m. f. developed by the thermocouple. This, however, is not the case. Experiments show that small differences of separation do not effect the value of the e. m. f. generated or developed at the junction. The explanation of the phenomena is found by considering the transfer of heat from small wires in gases, as explained by Irving Langmuir, and given elsewhere in this paper. It has been found that loss of heat from wires by free convection takes place as if a gaseous film surrounded the wire and the heat was transferred by conduction

through this film. It has also been determined that the thickness of the film is independent of the temperature but is dependent upon the diameter of the wire. Evidently, if other factors be assumed constant, a steady transfer of heat from the heating filament to the thermo-junction will be obtained, if the junction be arranged so that it always remains within the gaseous envelope surrounding the heater.

The characteristics of both junction and heater wire must be carefully considered. The heater wire should be of small diameter and of material having a high resistance and capable of withstanding considerable strain when heated to a cherry red. Tungsten wire .07 mm. or 3 mils in diameter was found to meet these requirements and gave the proper temperature with a current of about 40 milliamperes. Erperiments indicate that cells constructed with a heater wire of larger diameter do not remain constant. A heating filament of about 1cm. in length and having a resistance of approximately 12 ohms has given good results.

The couple wires should have as small diameter as possible in order to decrease the conduction of heat, reduce the lag to a minimum and to permit reaching a maximum temperature. The couple and heater wires are mounted on a single glass stem and after an adjustment of their relative positions has been made, this working unit is placed in the glass bulb.

USE OF GAS IN BULB:

If we produce a high degree of exhaustion in the bulb, a low thermal e. m. f. must result. Conversely, if the bulb is filled with gas under pressure, the junction will develop a high thermal e. m. f., the temperature of the filament being the same in both cases. In the first case the transfer of heat by convection is practically eliminated, leaving only the loss of heat by radiation from the small heater wire. This is negligibly small up to a temperature of several hundred degrees. In the second case, the heat is transferred so rapidly by convection that a high current value is required for the heater. Besides affecting the thermal e. m. f.,

the amount of gas is an important factor in the operation of the cell. Experiments have shown that if the amount of gas exceeds a certain value, the cell becomes very sensitive to even slight changes in position. The thermal e. m. f. increases as the junction approaches the point directly above the heating filament.

Nitrogen gas under a pressure of about 2 cm. has given good results. It permits the operation of the cell in any position, and a transfer of heat sufficient to produce the required e. m. f. In the construction of the cell, the bulb is first exhausted to about .4 microhms. It is then heated to approximately 350 degrees centigrade to eliminate moisture, at which time the gas is admitted and the bulb sealed off. A second filament,heated to a high temperature for a few minutes is used to eliminate the impurities in the gas.

AGING OF THE FILAMENT:

After the bulb has been assembled, the current is passed through the filament, raising its temperature to a point considerably beyond the final

operating value. This ages the filament and increases the permanency of the cell. Experiments were made to determine if it were possible to age the heating filament wire before placing in the bulb. This did not seem to produce the desired aging effect, even when heating the filament to a high temperature in gas. Possibly the wire was aged, but the handling necessary to assemble it in the bulb, may have resulted in mechanical strains sufficient to nullify the aging. Tests are then made to determine the proper values of R and R_1, also the amount of positive temperature coefficient metal to be inserted in the balancing resistance.

CONNECTIONS BETWEEN BULBS AND BINDING POSTS:

Any lag in the temperature of the balancing coil with respect to that of the heater and the couple wires is prevented by spiralled connections. By spiralling the connections from the bulb to the binding posts on the top of the cell, the heat conducting path is lengthened, so that changes in the surrounding temperature have a uniform effect on all parts of the cell. The characteristics of the Thermo-

electric Cell may be summed up as follows:

The e. m. f. obtainable from this cell is not limited as in other types. The drop resistance may be adjusted so that the potential across it can have any desired value, usually one volt. Any combination of e. m. f. values, however, may be obtained by taking taps from the drop resistance.

TEMPERATURE COEFFICIENT:

As previously shown, the temperature coefficient may be reduced to zero.

EFFECT OF TEMPERATURE:

The surrounding temperature may vary from values below zero degrees centigrade to over one hundred degrees centigrade, without the slightest injury to the cell. This is due to the fact that no liquid is used in its construction.

EFFECT OF SHORT CIRCUIT ON CELL:

When these cells are properly constructed they cannot be damaged by short-circuiting any of the external connections.

ACCIDENTAL INCREASE OF FILAMENT CURRENT:

An excessive current through the filament

may change the standard value of e. m. f. but will not necessarily destroy the usefulness of the cell. This effect will be more fully considered under "Results of Tests."

POSITION OF CELL:

The standard e. m. f. of the cell is not affected by the position of the cell.

STRENGTH OF CELL:

The cells are readily portable and will stand severe shocks without injury. They can be easily shipped if ordinary precautions are taken in packing.

ACCURACY:

Due to the fact that a null method is employed in balancing the cell, the observation error will be a minimum one. The principle sourcesof error are the temperature coefficient of the cell and the thermal e. m. f.'s other than the e. m. f. developed at the thermo-junction. The error due to thermo e. m. f.'s in the galvanometer circuit may be reduced to a minimum by short-circuiting the galvanometer circuit at the standard cell. The galvanometer will then

indicate the true zero, which must be used in obtaining the balance of the cell. Furthermore, any error in the thermo-junction circuit introduces but half the per cent of error in the potential measured across the drop resistance. As previously stated, this is due to the fact that the thermal e. m. f. of the junction circuit is proportional to the square of the current through the filament, whereas the potential across the drop resistance is directly proportional to this current. A standard thermo cell that is properly constructed and operated should remain constant to at least 5 parts in 10,000. It is probable that in view of the possibilities of improvement, the constancy of these cells will be greatly improved.

PERMANENCY TESTS:

In curve sheet No. 10 the results of tests on standard thermo cells are shown. These tests covered a period of 14 to 23 months and are representative of a considerable number of cells. The table on the following page, gives results of these tests in tabular form.

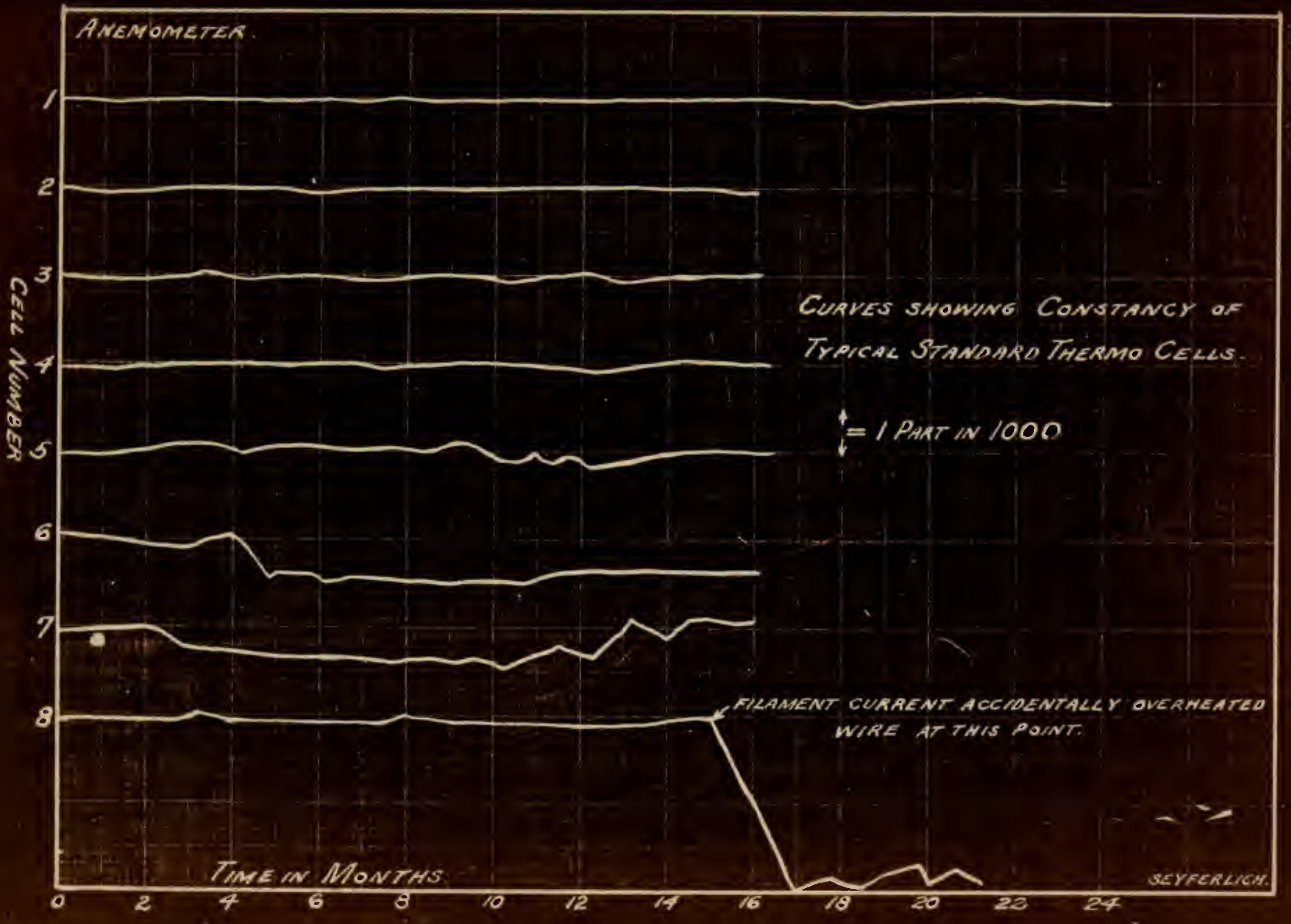

ANEMOMETER.
CURVES SHOWING CONSTANCY OF
TYPICAL STANDARD THERMO CELLS.
= 1 PART IN 1000
FILAMENT CURRENT ACCIDENTALLY OVERHEATED
WIRE AT THIS POINT.
CELL NUMBER
1
2
3
4
5
6
7
8
TIME IN MONTHS
0
2
4
6
8
10
12
14
16
18
20
22
24
SEYFERLICH.

TABLE NO. 19.

Cell No.	Original e. m. f.	Maximum variation Parts in 10,000	Avg. variation from orig. e.m.f. Parts in 10,000	No. of tests	Period covered by tests. Months
1	0.9890	2.0	0.0	27	23
2	1.0199	5.0	1.4	21	14
3	1.1294	3.0	1.0	16	15
4	1.0645	4.0	1.1	20	16
5	1.2004	4.0	1.4	14	14
*6	1.0376	3.0	0.2	5	4
#6	1.0371	4.0	0.4	14	11
7	1.1833	6.0	2.1	14	12
*8	0.9828	5.0	2.0	17	15
#8	0.9791	4.0	1.6	9	7

*Before filament temperature was accidently increased to reddening point.

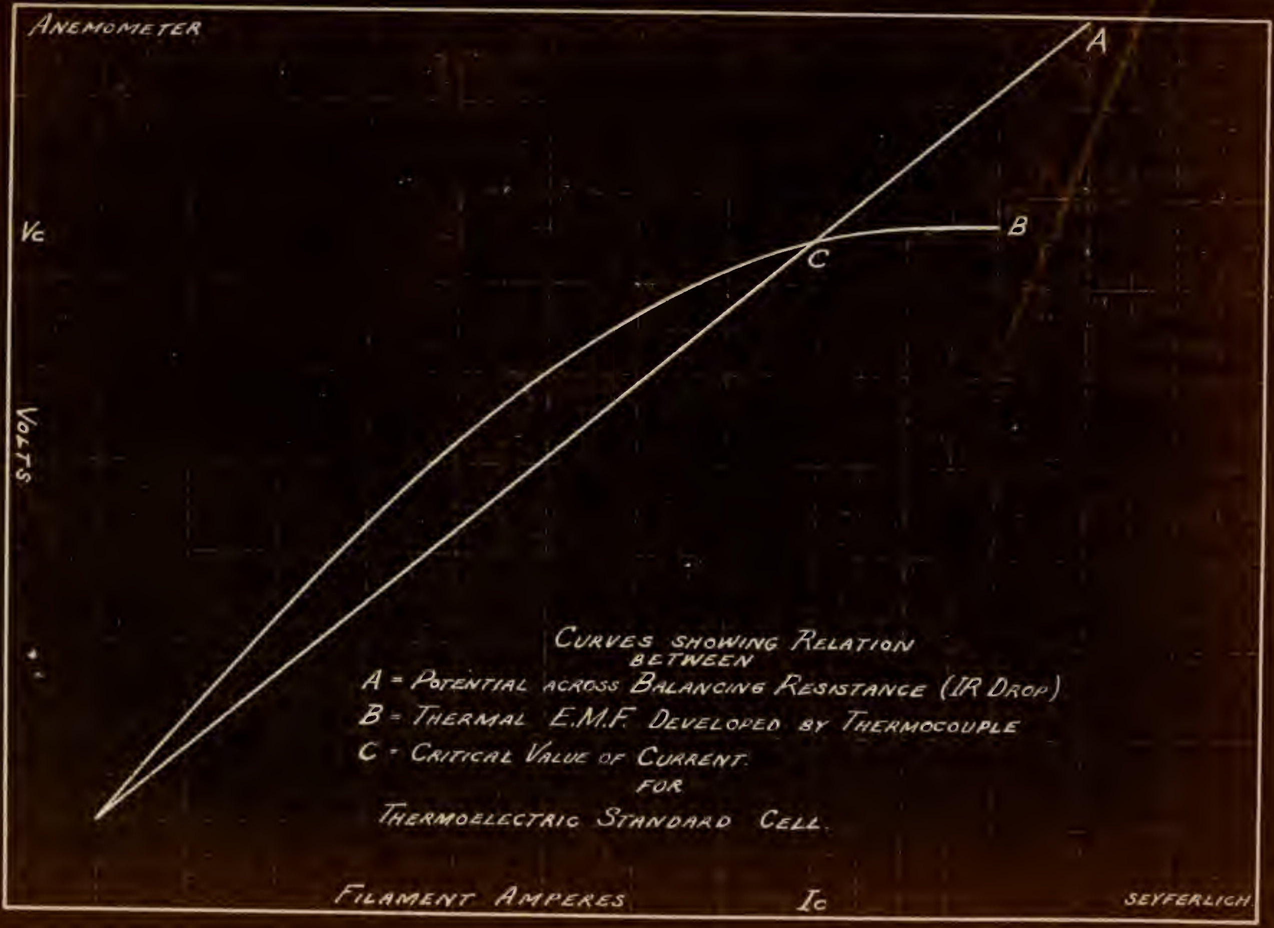
#After filament has been brought up to reddening point.

****

RESULTS OF TESTS:

The curves for cells Nos. 6 and 8 indicate the effect of increasing the filament temperature above the reddening point. As previously stated, this produces a permanent increase in the filament resistance. It follows that when the filament resistance is increased, the heater current must be decreased to obtain the new balancing point C. See Curve No. 11. This decrease in current of course results in a smaller potential across the drop resistance. It is interesting to note, that after the heating filament resistance has changed, the cell continues to function properly except that a lower value of e. m. f. is obtained, assuming of course, that the drop resistance is not changed. In the event of an accident of this nature the standard e. m. f. may be restored to its original value by adjusting the drop resistance.

In conclusion, it is believed that the characteristics of standard thermoelectric cell justify its use in many measurements in which primary standard cells are now used. This cell has



CURVES SHOWING RELATION
BETWEEN
A = POTENTIAL ACROSS BALANCING RESISTANCE (IR DROP)
B = THERMAL E.M.F. DEVELOPED BY THERMOCOUPLE
C = CRITICAL VALUE OF CURRENT
FOR
THERMOELECTRIC STANDARD CELL.

been successfully used with potentiometers designed for thermocouple works and would seem to present great advantages, as mentioned before, where relatively high or low temperatures are to be encountered.

In the past few years several of these potentiometers have been in constant use, and have been operated by unskilled labor. During this period no particular trouble has been experienced that could be charged to the standard cell. Several cells have been burned out through carelessness of the operator. In every case of a damaged cell it has been found that either the galvanometer or the slide wire or both were destroyed.

Another great advantage embodied in the thermoelectric cell is the fact that a very low resistance cell can be readily constructed. In fact the values given above are lower than that of the unsaturated, and decidedly lower than the saturated Weston cell. That is a point which is of great importance in selecting a suitable galvanometer for use with the deflection potentiometer. The pivoted rather than the suspended galvanometer is preferable.

With reference to the cold junction of the cell, it should be understood that both cold junctions are within the bulb. The copper wire used is very short, and extends from the center of the bulb, and about one quarter of an inch apart, or in other words, a half a millimeter or little more in each side is the cold end, so that all is contained within the bulb and the cell remains definite at all times.

****

THE ANEMOMETER AND ITS APPLICATION TO METEOROLOGICAL MEASUREMENTS.

One of the purposes of organizing the Army Meteor and Aerological Service in August 1917 was to "undertake for the first time in the history of the world the problem of mapping the upper air currents over the United States, the Atlantic and Western Europe in aid of Aviation, and particularly with reference to transatlantic flight.

Over twenty-six meteorological stations have been established and placed at carefully selected points over the whole United States. These stations have been manned by trained observers who telegraph to Washington each day observations on wind velocities at all altitudes up to 35,000 feet. In one instance these observations have been carried to 65,000 feet. On the basis of these observations, a daily forecast of upper-air winds is now being issued. The use which such forecasts may serve, both in connection with the aviation mail service and ultimately with the transatlantic service may be seen from the fact that above the level of 10,000 feet 95% of the winds in both the United States and

Europe are from West to East, and often attain velocities in excess of 100 miles an hour.

On November 6, 1918, at Chattanooga, Tenn. a velocity of 154 miles an hour at an altitude of 28,000 feet was observed. It is because of this easterly direction of these upper air currents that all of the long flights thus far made have been from West to East. The importance of a forecast of such currents for the purpose of long flights will be appreciated as soon as the foregoing facts are understood.

An airplane capable of a velocity of 154 miles an hour in still air would either remain stationary or travel at 308 miles an hour, depending on whether it were headed with or against a wind of the velocity of that observed at Chattanooga.

The problem of exploring the upper air currents over the Atlantic was at first thought insoluble on account of the absence of fixed bases, but the Meteorolohical Service has developed propaganda balloons which already have flown at an average altitude of 18,000 feet from Omaha to New Jersey, a

distance of more than a thousand miles. The success of the project now has made possible the mapping of the upper air highways across the Atlantic; for arrangements are being made to send up from both coastal stations and from transatlantic steamers, these long-range balloons designed for from two to three thousand mile flights and adjusted to maintain a constant altitude and to drop in Western Europe their records of average winds in these thertofore unchartable regions. The importance of this work for the future of aviation needs no emphasis.

****

A HOT-WIRE ANEMOMETER WITH THERMOCOUPLE AT MID-POINT.

Among the most recent of these researches in Anemometry are those of Dr. T. S. Taylor, Research Physicist in the Westinghouse Research Laboratories. In a series of papers describing "A New Hot-Wire Anemometer with Thermocouple," he had compared the results of the thermocouple-type with those obtained by the use of a modified form of the resistance-type used by Kennelly, King, etc. It was with the object of measuring the rate of gas flow through relatively small tubes, where the velocity values change rather rapidly, and vary considerably from point-to-point across the tube, that led Dr. Taylor to devise the convenient form of anemometer involving the use of a thermocouple.

As indicated in figure 33, this type of anemometer consists essentially of a fine platinum heating wire H I stretched across a suitable framework A B C D E, say of glass, fibre, or some other insulating material. At the central point of this heating wire H I,

[illegible]

[illegible]

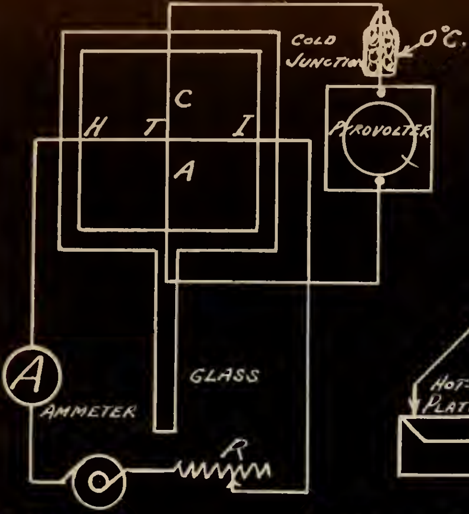
[illegible]

[illegible]

there is attached a copper-constantan thermocouple F T G, made up of very fine wire, in order that heat-conduction be a minimum. The platinum heating wire H I is about .007 inch or .178 mm. in diameter, and from 1/2 to 1 inch, or 12.7 to 25.4 mm. in length. The copper-constantan thermocouple wires are about .002 inch or .05 mm. in diameter.

In using this form of instrument, it has been found quite satisfactory to measure the current required to maintain the temperature of the wire, as determined or indicated by the thermocouple, say 200° C. or 300° C. above the temperature of gas in which it is placed. The temperature values indicated by the thermocouple may be measured by any of the methods given under "Methods of Measurement," such as the thermocouple potentiometer indicator, sold by Leeds & Northrup or the Pyrovolter Instrument Company. The values of current may likewise be obtained by the use of a first class ammeter or by means of a standard resistance and potentiometer system. By using this method it is possible to measure quite accurately the velocity of gases at various temper-

HOT-WIRE ANEMOMETERS.



HOT-WIRE ANEMOMETER WITH THERMO COUPLE AT MID-POINT

FIGURE 33.

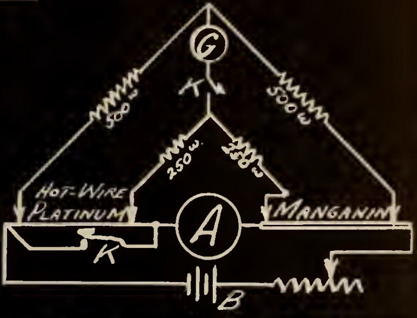
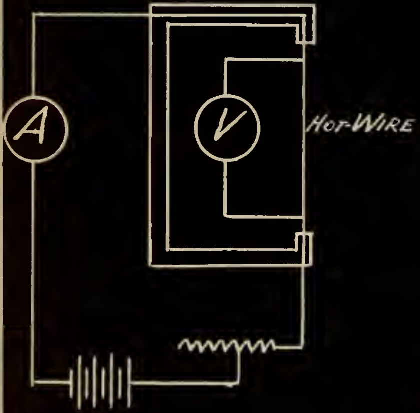
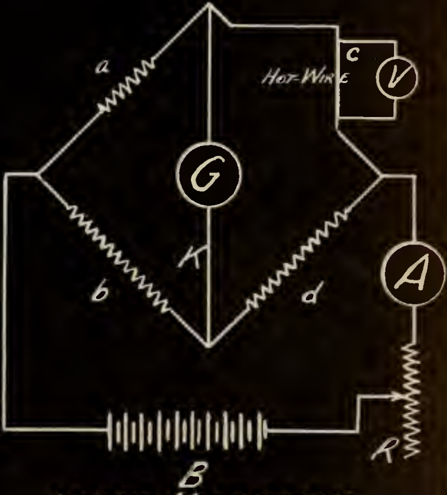


DIAGRAM OF ARRANGEMENT USED BY L. V. KING.

FIGURE 34.



DIRECT MEASUREMENT
FIGURE 35.



INDIRECT MEASUREMENT
FIGURE 36.

RESISTANCE TYPE OF HOT-WIRE ANEMOMETER USED BY KENNELLY.

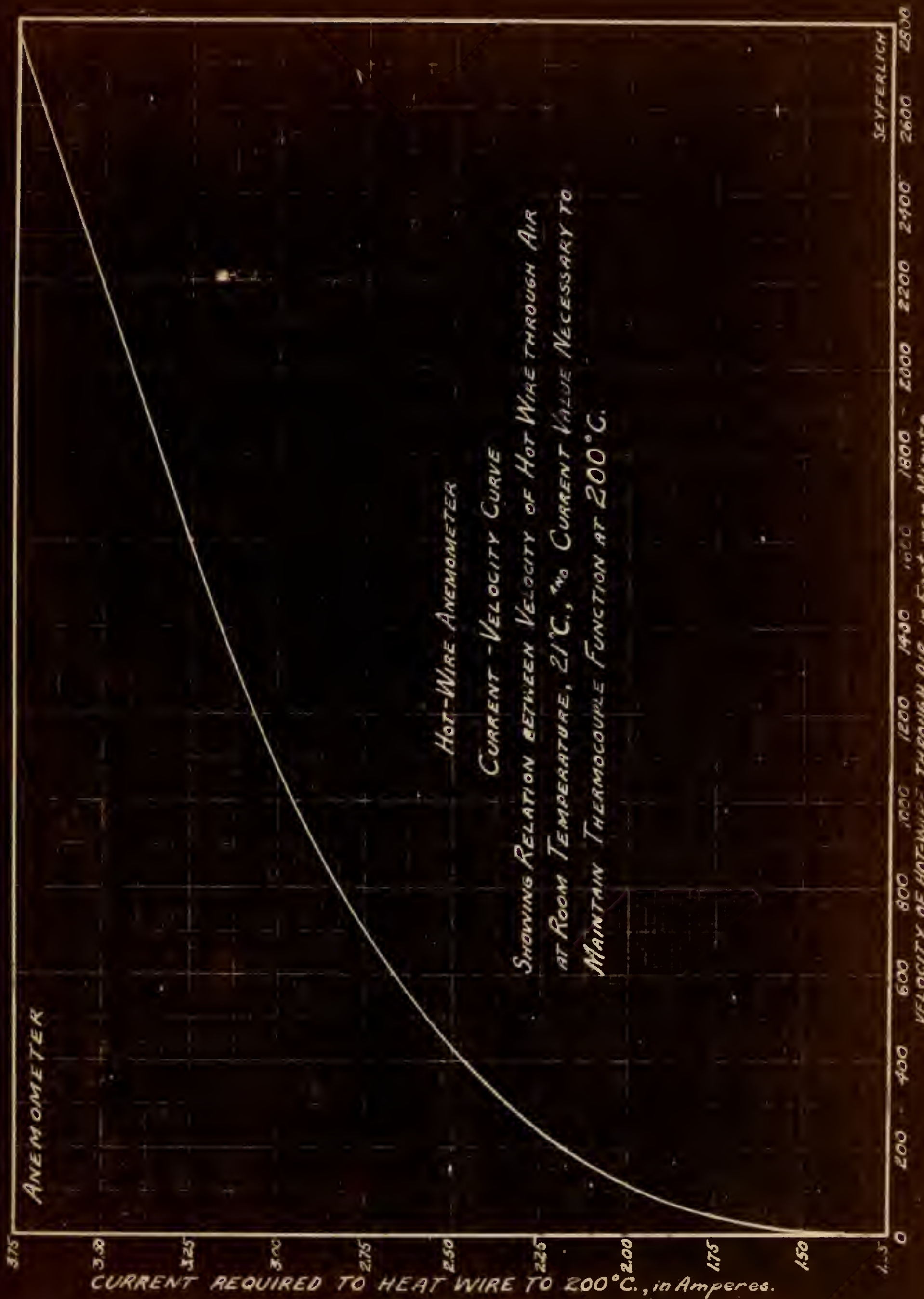
atures, and has the great advantage of really measuring the velocity of gas at a point. It also facilitates the measurements greatly and avoids the possibility of accidentally burning out the heating wire.

This anemometer can be so arranged that it may be placed in various positions in a tube of most any size, and yet not interfere seriously with the air velocity under measurement. The heating wire can be coiled and made to occupy a relatively small area, or it may be stretched straight as indicated in the figure. By means of the thermocouple the temperature of the gas at the point where the value of the velocity is desired, may be readily obtained directly, when there is no current flowing through the heating wire. If direct current be used in heating the hot-wire H I, the mean value of the readings obtained for current flowing in each direction should be used; this will avoid the possibility of any error arising, due to the thermocouple wires not being at exactly the same point on the heated-wire. This error may be entirely avoided by the use of alternating current

for the heating filament.

As in the consideration of other types of anemometers, it is necessary to calibrate the thermocouple-type under the conditions that it is to be used.

If the instrument is to be used in measuring air velocities at ordinary temperatures, it may be calibrated in a manner similar to that described by King and Kennelly. In other words, calibration curves may be obtained by placing the anemometer on a revolving arm, the speed of which may be varied at will. From the results of such a calibration, a curve may be plotted showing the relation between the speed of the wire through air at room temperature of about 21° C, and the current required to maintain the thermocouple hot-junction at a temperature of 200° C., as shown in curve No. 12. The abscissas represent the values of velocity in feet per minute, while the ordinates represent the corresponding values of current in amperes, required by the heating-wire to maintain the hot junction at 200° C. The data for this particular curve was


ANEMOMETER
SEYFERLICH
HOT-WIRE ANEMOMETER
CURRENT - VELOCITY CURVE
SHOWING RELATION BETWEEN VELOCITY OF HOT WIRE THROUGH AIR
AT ROOM TEMPERATURE, 21°C., AND CURRENT VALUE NECESSARY TO
MAINTAIN THERMOCOUPLE FUNCTION AT 200°C.
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
VELOCITY OF HOT-WIRE THROUGH AIR, in Feet per Minute.
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
CURRENT REQUIRED TO HEAT WIRE TO 200°C., in Amperes.

obtained by revolving the anemometer on an arm $4\frac{1}{2}$ feet or 1.37 meter long about a vertical axis. Such a device does not give a very uniform swirl to the air.

More recent work has been done in calibrating the anemometer by placing the instrument at a point on the circumference of a revolving disk $2\frac{1}{2}$ feet or .762 meter in diameter. Such an arrangement gives a very uniform swirl to the air and hence the anemometer readings may be accurately corrected by revolving the disk when the anemometer is in a stationary position. The revolving disk can also be placed in a oven so that the anemometer can be calibrated in the air at various temperatures, say up to 100° Centigrade at least, and possibly as high as 200° Centigrade.

The thermocouple type of anemometer,as mentioned above, possesses the great advantage of really measuring the velocity, and hence total-gas-flow at a point, and at the same time presents a convenient method of measuring the gas flow in places where the temperature as well as the velocity

of the gas is changing from point to point. Such conditions would exist, for example, in a tube having a heater wound around it.

In the calibration of the anemometer, the current and thermocouple connections are made to the anemometer by means of slip rings and contact brushes on the revolving shaft. It was not found necessary to use low-resistance mercury contacts, as is the case when the resistance measurements are made by means of a Kelvin bridge, as was done by King and others. Occasional parasitic currents, due to imperfect brush contact and temperature changes, arose in the calibration of this type of anemometer but these errors were readily detected and eliminated by means of the method of reversals of current, and also by noting the thermocouple readings where the anemometer heating wire has no current flowing through it.

By the use of an accurate thermocouple potentiometer, for measuring the temperature of the wire and a potentiometer for measuring the values of the heating current, very accurate velocity measure-

ments can be obtained. In using this instrument, however, it is necessary first of all to measure the temperature of the air or gas by means of an attached thermocouple at the point in question before putting any heating current through the platinum wire, and then to measure accurately the value of the current necessary to maintain the heating wire, say 200° or 300° C. above that of the air or gas in which it is placed. This of course requires the maintenance of a constant temperature at the cold junction of the thermocouple. In all the measurements described the cold junction was kept at zero degrees centigrade, as given by Dr. Taylor in a personal communication to the author under date of March 21st, 1921. It was also pointed out in said communication that the main disadvantage in the use of such an anemometer would arise where it is desired to measure the component velocity in a streamof turbulent flow. In this case the anemometer would indicate the velocity values in all directions and therefore it would be rather difficult to select the correct

reading. This feature of the instrument, however, would, in certain applications, be deemed more of an advantage than a disadvantage, for example when used as an anemometer for measuring wind velocities out of doors. In that case a heating wire stretched vertically would indicate correctly the wind velocities at the point in question regardless of how fast the direction of the wind might change. This, of course, would give this type of instrument a great advantage over the various types developed to date.

In a second letter from Dr. Taylor, it was pointed out that pitot tubes were given preference in his particular line of work, owing to the difficulty in calibrating the hot-wire anemometer described above, as well as the troubles arising in connection with maintaining the current constant or measuring the resistance. He stated that in general all the manipulations were rather tedious for commercial work.

In addition to the thermocouple-type of anemometer described above, it was also found

that a resistance-type similar to the ones used by Kennelly, King and others, could be used quite satisfactorily in velocity measurements in small tubes. Instead of having the leads for resistance measurements to the heating wire placed far apart, say 10 centimeters or more, they were placed close together. Then, in calibrating and using the anemometer, the potentiometer is used to measure the drop between the potential leads. This drop is maintained constant for all velocities and the values of the current necessary to maintain this potential-drop at a constant value is observed. The potential leads between which the potential drop is measured, should be of as fine a wire as possible in order to avoid unnecessary loss of heat by conduction. The latter type is a little easier to construct, as it is somewhat easier to weld one small platinum wire to a larger sized wire of the same material than it is to weld a small copper-constantan thermocouple junction to a larger sized platinum wire and get the two wires of the hot junction at exactly the same point on the platinum wire. The

distribution of gas flow in small channels and tubes of various sizes and shapes were to be studied by means of the anemometer described above, but,as stated before, the work was abandoned in favor of the pitot tube constructed from hypodermic needle tubing.

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METHOD OF WELDING THERMOCOUPLE WIRES.

ELECTRO PERCUSSIVE WELDING.

****

The soldering and welding of aluminum has always given trouble and the satisfactory joining of small wires is very difficult if not impossible.

In the last few years, the substitution of aluminum wire for copper wire has demanded a good reliable means of joining aluminum, and the electro-percussive method of welding was developed primarily for this purpose after a very thorough investigation into the available methods of soldering and welding, with special reference to aluminum. Several other special applications of the method are now made and the future field of applications seems sufficiently promising to justify a description of this new process, which will enable the welder to weld practically any two metals, whether alike or entirely different, of high or low melting point, or of unequal thermal conductance.

In the case of aluminum the natural oxide

which always covers the surfaces of the two pieces to be welded, prevents the metal from flowing together after the ends have been melted in the usual manner. Large wires and rods of aluminum can be welded by melting the metal under the oxide film and then suddenly pushing the ends of the two pieces together. This breaks the oxide films and allows the clean metal to flow together, and at the same time washes away the broken pieces of oxide in a surplus of molted metal. Small wires, however, cannot be joined satisfactorily by this method, or, in air by any other prolonged heating method, because of the skill required and also because such joints in small wires, if made, are oxidized to such an extent that they are brittle and weak.

As early as 1905, Skinner and Chubb, while experimenting with electrolytic condensers and rectifiers, noticed that wires could be connected to the aluminum plates by the condenser spark when the cells were discharged. It was noticed then that copper wires could be attached to aluminum or that

two pieces of aluminum could be joined together by the condenser discharge spark. This was, of course, only a feeble welding of the metals for temporary connections. But later on, while working with aluminum wire, the demand for a welding method and a careful theoretical consideration of what happened in the early tests with electrolytic condensers made it appear worth while to try out the method of welding on a larger scale with a condenser discharge.

From the first, the same principle of a simultaneous condenser discharge and percussive engagement has been used, but during the tests and development of welding tools it was found that the best results depend upon the values of several variables, such as the condenser capacitance, the velocity and force of impact, the voltage, and the resistance and inductance in the circuit.

The first apparatus consisted of two hinged arms with wire grips in their ends. Wires placed in the grips were connected to the terminals of a charged electrolytic condenser. These arms,

ANEMOMETER SEYFERLICH.

DIAGRAM OF CIRCUIT USED IN ELECTRO-PERCUSSIVE WELDING

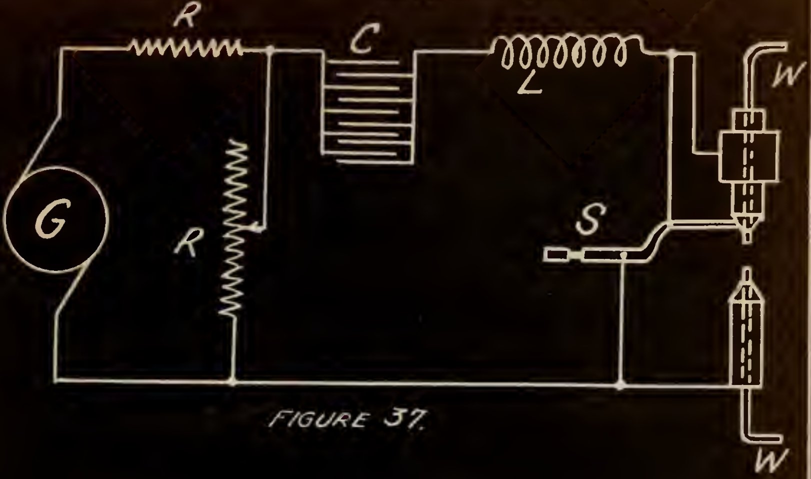


FIGURE 37.

VARIOUS STAGES THAT TWO WIRES PROBABLY UNDERGO IN ELECTRO-PERCUSSIVE WELDING

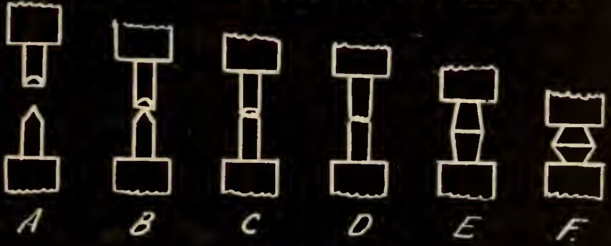


FIGURE 38.

upon release, were drawn together by means of a rubber band, and, at the instant of contact, the explosive condenser discharge and the forge would weld the ends together. This apparatus was not very satisfactory, as it did not allow separate study of the effect of variation of velocity, momentum, kinetic energy, etc. A second device was built similar to a pile driver, with one stationary and one moving wire grip. With this arrangement the forge and velocity could be varied independently by the separate adjustment of the drop and mass of the moving part. Other welding tools were also designed in which springs were used to shoot the wire grips together horizontally; however, these have not been as satisfactory as the gravitational type.

The welding circuit as indicated in figure 37 consists of a direct current line or generator G, which charges an elecyrolytic condenser C through a high resistance R. Adjustment of the voltage of the charged condenser is obtained by field control of the generator or by varying the values of the resistances R and R^1. The wires W W to be welded are secured in

the wire grips of the welding tool, the grips being connected to oppositely charged terminals of a condenser through an inductance L, which may consist of from 2 to 10 turns of heavy cable. A spring switch S having carbon contacts normally held closed, is connected across the jaws of the welder so that their potential difference will be zero while the wires are being put in or the finished product is being removed. The welder is connected to the auxiliary apparatus by means of long flexible cables, which allow welding within a radius of about 50 feet without moving the condenser and other heavy apparatus.

The process of welding is as follows: The wires to be welded are secured in the wire grips and the ends cut off as short as possible with a suitable pair of cutters. The switch S is then opened, which charges the condenser to the proper voltage, a catch is then released which allows the sliding member to fall and bring the ends of the two wires into percussive engagement. At the instant of contact the short circuit current of the condenser

builds up to such a value that the ends of the wire are melted by the explosive discharge and instantly forged together by the blow of the falling mass. The weld is then complete and after being removed from the machine will be found to have the strength of the original wire.

The generation of heat is so localized, so sudden, and so intense that there is no time for unequal heat conduction through the shanks of the wire and the ends will be melted and even vaporized whether the melting point is high or low. For this reason metals of different kinds can be welded together independent of the values of their electrical resistance, melting point, or heat conductivity. Any combination of metals which has ever been tried will weld successfully but the joints will not be permanent with such combinations as aluminum and tin, or lead and iron.

The generation of heat at the point of contact depends upon having an appreciable resistance offered to the current between the wire ends, and it is, therefore, necessary to cut the ends of the wires

in such a way that they will make a point contact preferably at the center, so that the energy of the condenser discharge will vaporize the small section of metal and wet the rapidly approaching surfaces with the intense heat of the arc. To do this the wires are cut with ordinary cutters, which give a chisel edge. The two wires are cut off in such a way that the two chisel edges are at right angles and the point of contact will be at the intersection of the center.

The actual time between the first contact and the finished weld is of such short duration that the exact action cannot be recorded, but is supposedly as shown in figure 38. In position (a) the wires are approaching at a velocity of from 65 to 200 cms. per second. Position (b) shows the first contact at which time the current begins to build up and heat the small section of metal carrying the current, (c) shows the wire ends again separated, not by appreciably retarding or reversing the motion of the upper wire, but by melting and vaporizing the metal which first touched together. (d) shows the wire chucks closer

APPARATUS USED IN WELDING SMALL WIRES.

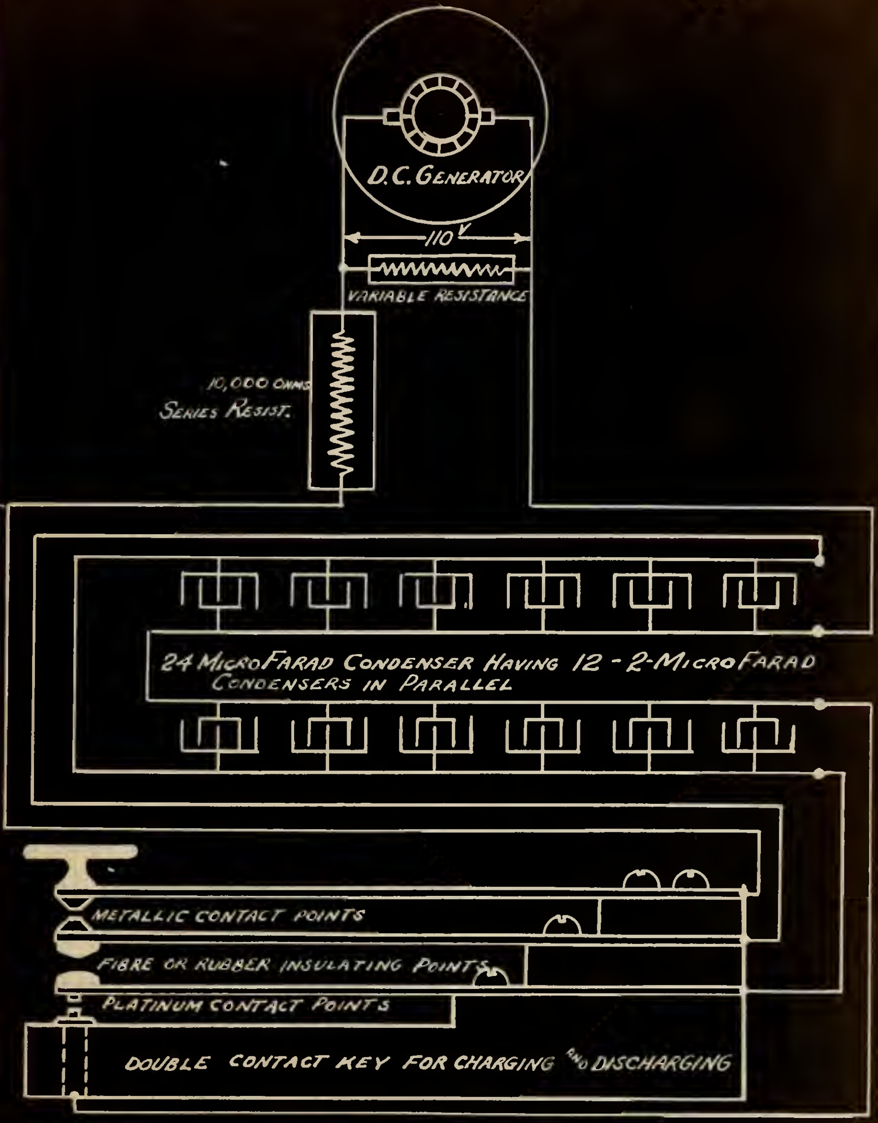
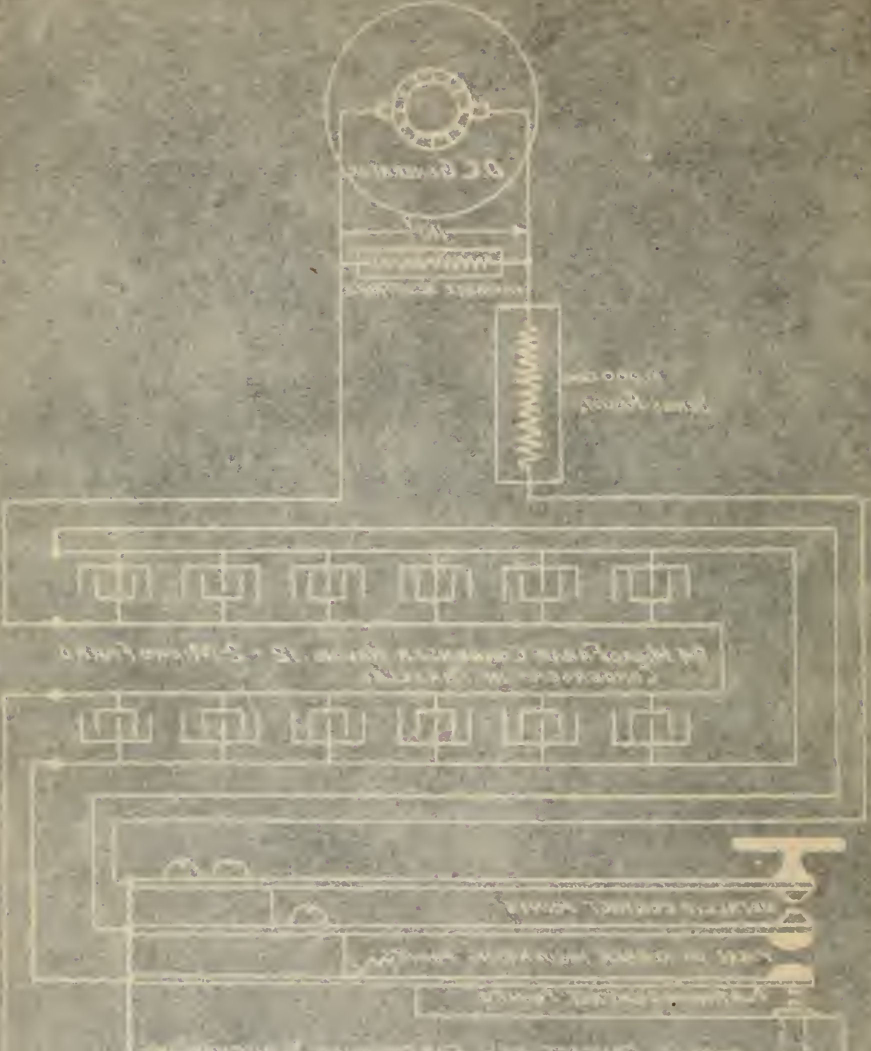
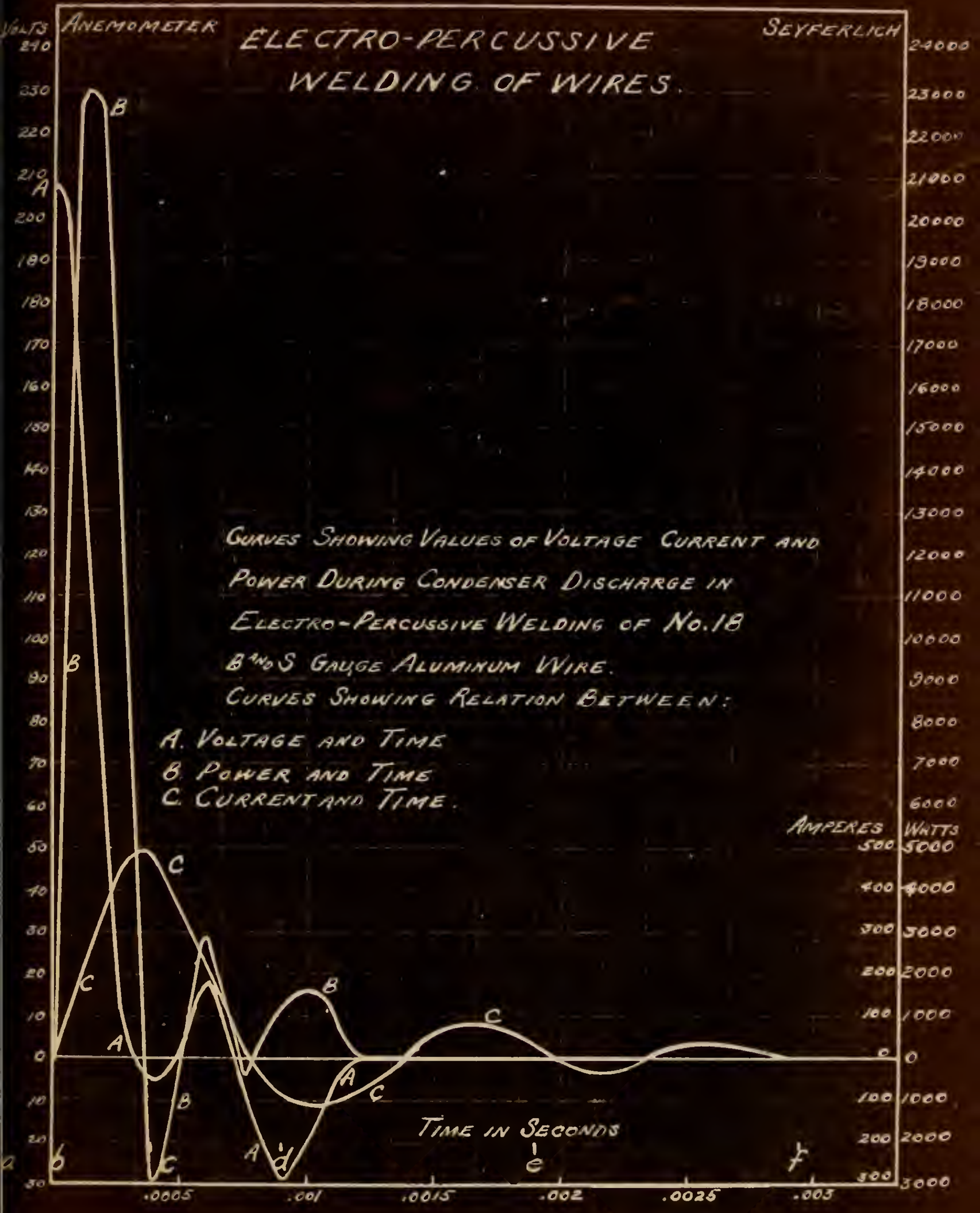

D.C. GENERATOR
110V
VARIABLE RESISTANCE
10,000 OHMS
SERIES RESIST.
24 MICROFARAD CONDENSER HAVING 12 - 2-MICROFARAD CONDENSERS IN PARALLEL
METALLIC CONTACT POINTS
FIBRE OR RUBBER INSULATING POINTS
PLATINUM CONTACT POINTS
DOUBLE CONTACT KEY FOR CHARGING AND DISCHARGING

FIGURE 39.



together but the arc still burning between the wires. At (e) the second contact has been made, the arc extinguished and the forge of the metal has begun. (f) shows the completed weld after the upper chuck has come to rest and the forge is complete.

The curves on the following curve sheet, drawn to scale, show the current throughm and the voltage across the weld during the operation of welding a No. 18 B. & S. Gauge wire. These curves were obtained directly from an oscillogram, and the power or product curve has been computed and drawn in to scale. Electrically the weld is complete in .0012 of a second and although 23 kilowatts are being dissipated between the ends of the wire at a certain instant, the total energy used at the weld is only .00000123 of a kilowatt-hour, or enough energy to light an ordinary 50 watt, 16 candle power lamp for .09 of a second. The cost of this amount of energy at 10 cents per kilowatt hour would be 12 millionths of a cent. The letters a, b, c, d, e, and f have been placed along the time axis of the curve sheet to indicate approximately the time corresponding to the various views represented in figure 38.


ELECTRO-PERCUSSIVE
WELDING OF WIRES.
ANEMOMETER
SEYFERLICH
CURVES SHOWING VALUES OF VOLTAGE CURRENT AND
POWER DURING CONDENSER DISCHARGE IN
ELECTRO-PERCUSSIVE WELDING OF NO. 18
B AND S GAUGE ALUMINUM WIRE.
CURVES SHOWING RELATION BETWEEN:
A. VOLTAGE AND TIME
B. POWER AND TIME
C. CURRENT AND TIME.
VOLTS
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
24000
23000
22000
21000
20000
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
AMPERES
WATTS
500
5000
400
4000
300
3000
200
2000
100
1000
0
0
100
1000
200
2000
300
3000
A
B
B
C
C
A
B
C
A
B
C
A
C
A
a
b
c
d
e
F
TIME IN SECONDS
.0005
.001
.0015
.002
.0025
.003

It will be noticed that the watt curve is oscillatory and that the negative values would indicate a return of stored energy. Such a condition would be impossible from a metallic arc. but can be explained by saying that the voltage was measured above and below instead of between the wire chucks, and the storage and return of energy is from the magnetic flux produced in the steel chucks set up by the current of 500 amperes flowing through them.

The electrolytic condenser has high absorption if the current through it is reversed in an attempt to change its polarity. For this reason any tendency toward an oscillatory discharge will be quickly damped by the internal losses of the condenser and the energy of the charge will be partly lost.

Enough resistance cannot be maintained at the weld to sufficiently prolong the current and heating until the final contact, and the very high frequency oscillation due to the small inductance in the circuit will cause an explosive snap at the weld, the current will suddenly be damped by the absorption of the condenser, the arc will go out before final con-

tact, and the wires will not be hot enough to form a good weld. In order to maintain the arc until final contact it is, therefore, necessary to lower the frequency of the discharge, and prevent the sudden rise of current at the first instant of contact by inserting additional inductance in the discharge circuit. This inductance prevents the explosive and wasteful discharge, prolongs the current, and apparently maintains the heating until final contact is effected. The inductance will, of course, increase the tendency toward oscillation and although the total energy dissipated at the weld may be diminished, it is more efficiently used and not wasted in noise or thrown out metallic vapor.

The equations expressing this interesting transient are not as valuable as the ear in telling what adjustments are best for any particular weld. The mass and drop of the falling chuck must be sufficient to slightly forge the wire and then all that is necessary is to change the voltage and inductance so that the discharge sounds like a splash or thud instead of a sharp crack. Generally, the

weld must range from 100 per cent. copper on one side to 100 per cent. aluminum on the other; but possibly the brittle conbimations are so thin that the joint as a whole is flexible and ductile. This joint between aluminum and copper is of great importance, as copper-lead wires, which solder and connect easily, can readily be attached to aluminum coils. At first it was feared that a diffusion of the two metals in service would finally result in a brittle joint, but tests show that after four years the joints are practically as strong and ductile as when first made. Similar ductility has been noted in almost every combination of metals when first welded, but diffusion, disintegration and loss of ductility eventually result in such welds as silver to tin, or aluminum to tin.

Metals which are either hardened or softened with heating and sudden cooling can be welded together without appreciable change in the physical properties of the material. Tempered spring steel welded, reduced to uniform diameter, and tested has shown equal or greater strength at and near the weld

without any noticable change in temper. Metals such as hard drawn copper, silver, aluminum, etc., which soften with heat can be welded together without causing any local annealing, and these metals and steel when soft can be welded together without detrimental local hardening.

Several possible explanations of the constancy of the mechanical properties before and after welding can be given. First, such sudden heating and cooling may not allow change in molecular structure. Second, with hard steel, the heated metal at the weld is so suddenly cooled by conduction of heat into the two shanks of metal that it is again hardened. Third, with hard copper, silver, aluminum, etc., the heating and sudden cooling would ordinarily soften the metal, but the cold forge of the blow in welding possibly hardens it again. Fourth, the metal subjected to the sudden heat cycle may be hardened or annealed, depending upon the characteristics of the material welded, but the amount of material affected may be too small to be detected. As an illustration, assume a No. 18 B. & S. Gauge hard drawn aluminum wire

to be welded to a second piece. As explained above, .00123 of a watt hour or 1.06 small calories are dissipated at the weld. Assume none of the energy lost in noise, radiant heat or metallic vapor, and one-half of the total propogated in a heat wave in each direction along the wire. It can be shown mathematically that an annealing temperature will not be reached more than .05 of a mm. from the weld. The total amount of metal softened would then be a cylinder .1 mm. long and 1.02 mm. in diameter. A soft insertion of such proportions could hardly be detected. An enlarged section of such a weld indicates that the disc of changed metal is only about .01 mm. instead of .1 mm. thick and physical tests fail to show any weakness or softness at the weld after being reduced to uniform diameter by removing the surplus metal of the burr. As indicated in a micrograph taken three years after welding, it became known that the line of the weld could not be seen and therefore either never existed or disappeared during the time that elapsed. In welds between some metals diffusion takes place, but in any

of the useful combinations the change is too slight to affect the ductility of the weld. The welds as a rule show only a sharp dividing line between the metals but there is often an intermingling of the two at or near the center for a very short distance.

It becomes evident that the electrical resistance of the two wires welded together will not be appreciably increased by the small film of high resistance alloy which may be formed in welding. Tests of a wire of 85 alternate pieces of aluminum and copper joined with 84 welds in a total length of 23.5 cms. showed an increase of .56 per cent. in resistance in three years. This test was made to determine whether or not diffusion would occur. The increase is small and may be due to a change in the joints or may be due to error of observation or oxidation of the wire. The sample was later rolled and its malleability indicated no appreciable change.

APPLICATIONS OF ELECTRO PERCUSSIVE WELDING:

While the development of this welding method was brought about primarily by the necessity

for the successful joining of aluminum wires, and the joining of copper leads to such aluminum wires, it is evident that the method is capable of an extremely varied application. Since metals varying as widely in characteristics as platinum and tin may be easily welded it follows that almost any metals may be joined where the joint is within the limits of the welding apparatus. While the welding apparatus referred to up to this time was made only for the welding of wires .072 of an inch in diameter and smaller, the application to the welding of larger sizes is merely a question of the design of suitable apparatus. Enough has also been done to show that welding other than the welding of wires may be successfully accomplished; as for example, the welding of points to plates and small pieces to irregular shaped objects or flat surfaces.

While it is not the intention to present here the possible applications of this method, it may be said that electro-percussive welding has already been used to a considerable extent in the joining of thermocouple wires, aluminum wires; the welding of

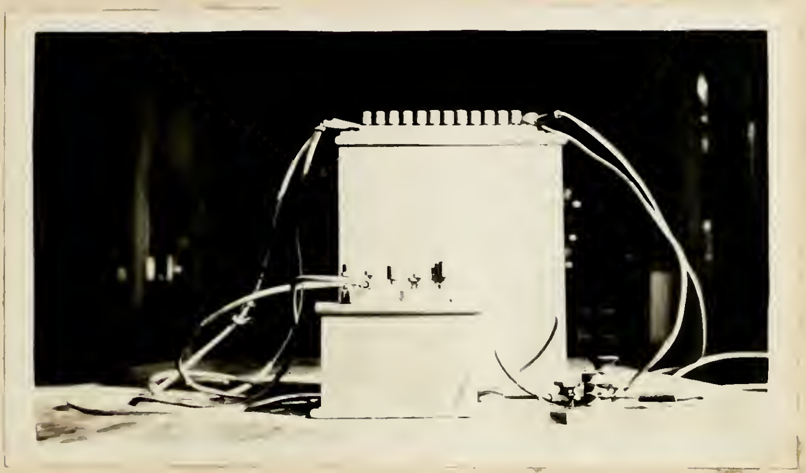
copper and aluminum wire; platinum and nickel; platinum and copper; and the welding of various thermoelectro arrangements such as the hot wire anemometer. It has also been used for the reclamation of short pieces of wires of various kinds, such as aluminum, platinum, spring steel, etc.

The electro-percussive method is suitable for many applications in the jewelry trade, such as the joining of platinum without showing any solder line; the welding of sterling tips to table forks without annealing; the welding of pins to badges, and many other similar applications. The attachment of contact points of platinum, tungsten, silver, etc., for various electrical purposes is also very readily accomplished.

It is the author's opinion that the electro-percussive method of welding will eventually open up a wide field of welding hitherto impossible. It also overlaps, to a certain extent, some of the present methods, but it will probably never supersede the existing methods for the welding of very large sections.

For very small wires and special arrangements such as those used in the Thermoelectric Fluid Meter,

FIGURE C



Resistance-Box, Condenser, and Double-Contact Key Used in Welding Thermocouple Wires.

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the author has, after considerable experimenting found the arrangement shown in figure   to give the most consistent results.

In welding wires of manganin and advance larger than a No. 40 B. & S. the double contact key was used so that sufficient pressure could be applied at the point of contact in order to obtain a strong and permanent weld. For the welding of wires of No. 40 B. & S. Gauge and finer this method was departed from, and the wires alone were used. In this case the terminals of the condenser were connected directly to the wires to be welded, and with the condenser undergoing a charge, the two wires were separated one of two remaining stationary, while the other was in a position to spring against the stationary wire immediately upon release and thus discharge the condenser. When the necessary tension in the "spring" wire was of the proper value and the capacity of the condenser was likewise of proper proportion with reference to the voltage and resistance of the circuit, very good results were obtained. It was also found that wires of any and all materials could be welded by this method.

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THE THERMOELECTRIC FLUID-METER
AND
LINEAR HOT-WIRE ANEMOMETER.

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It is well known that when an electrically heated wire is supported in air, it dissipates the heat produced, by the three modes of heat transmission, conduction, radiation, and convection.

Conduction occurs longitudinally through and into the metallic terminals of the wire, and would take place laterally through the air, if the latter were kept at rest like a rigid medium. The metallic conduction at the ends may be eliminated by confining observation to a section or point not near the ends. The lateral conduction through the air is negligible, because the air does not remain at rest but expands and flows convectively. Conductive thermal loss may therefore be ignored entirely as far as the heating wire is concerned.

When a thermocouple is to be used as the indicating means, the thermal condictivity and metallic conduction become of great importance, especially in the thermoelectric fluid-meter, in which the hot and cold junctions of the couple are separated by only a

short length of wire about 1/4 of an inch in length. The metallic conduction from hot to cold junction may thus be controlled to a great extent by the selection of proper material for the thermoelements and having them of very fine sized wire.

Radiation loss from the heated wire is a function of the surface area of the wire, its temperature, the nature of its physical surface, and the temperature of surrounding substances. For a given wire, having a given surface condition, and placed in a given environment, radiation loss may be regarded as a function of temperature only.

Convection loss from the wire is a hydrodynamic phenomenon, involving the flow of air past the surface of the wire, and the amount of heat which this moving stream of aur can carry off. Until recent years, very little was known quantitatively about convection. The most important researches made on the subject were those of Kennelly, King, and Langmuir, and a complete summary of their results is given in a later paragraph.

In order to study convection loss to advantage, and to make use of it effectively in the thermoelectric fluid-meter, it is desirable to experiment on small wires; because, for a given temperature elevation of the wire in air, the radiation increases in proportion to the surface area; whereas, the free convection is independent of the surface area to a first approximation. Consequently, a wire of small surface area per unit of length, or in other words a fine wire, will have relatively small radiation loss as compared with the value of its convective loss.

Convection may be divided into two classes; namely, free convection and forced convection.

1. Free convection takes place when the wire is supported in free still or quiet air; or air that is substantially free from draughts or eddy movements, except those produced by the heated wire itself.

2. Forced convection takes place when the wire is in motion relatively to the surrounding air; which means that either the wire be moved bodily

through the air, or be held in a stream of moving air.

An electrically heated wire is therefore subject to free convection when it is supported at rest in still air, substantially free from draughts or wind moting. It is likewise, subject to forced convection when it is either moved bodily through the air, or when it is placed in a draught or wind.

In order to separate convection loss from radiation loss, it is desirable to operate the wire under test at constant temperature as far as possible, and also at a constant temperature elevation above surrounding solid bodies. The radiation loss under these conditions will be constant, and therefore changes in the surrounding air will give rise to changes in heat dissipation that may safely be attributed to changes in convection alone.

THE THERMOELECTRIC FLUID-METER:

Since the operation of the Thermoelectric Fluid-Meter depends upon the principle of balancing the E. M. F. developed by a thermocouple against the potential or ir drop across a definite resistance

PLATE No.13. PAGE 266.

ANEMOMETER. SEYFERLICH

DIAGRAM OF CONNECTIONS. FOR THE THERMO-ELECTRIC FLUID-METER.

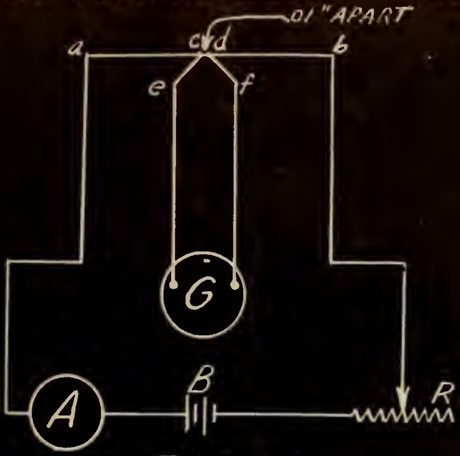


FIGURE 39.

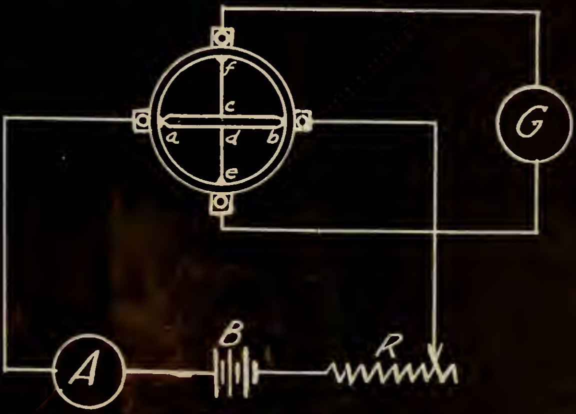


FIGURE 40.

wire, the instrument is essentially operated on direct current.

In one form of the Fluid-Meter, as indicated in figure 39, the battery B acts as a source of current for the electrically heated wire or filament ab, made of fine sized No. 36 B. & S. Gauge or smaller) advance. The value of current through the heating filament may be varied from zero to the maximum allowable heating-current by means of the adjustable regulating resistance R. The milli-ammeter A indicates the value of this heating-current which causes the rise in temperature of the fine resistance wire ab, the rise in temperature being directly proportional to the square of the current (i^2), as the resistance r does not vary by an appreciable amount.

At the central point of this heating filament there is welded or fused a fine wire of Therlo or Manganin, the length of which is made small, about an eighth or a quarter of an inch, so that the "cold" junction of the couple is subject to practically the same temperature changes as the "hot" except that produced by the heating-current itself. In other words, the temperature difference between the hot and cold junctions

is due only to the heating-current, and its value depends upon the rate of convection at the surface of the hot wire. This is true provided the heat conduction from the hot to the cold junctions be minimized and hence neglected. At a distance of about .01 of an inch from the hot junction formed by the advance heating wire and the Therlo or Manganin wire, is welded a second advance wire of the same gauge or smaller which forms the other lead of the galvanometer circuit. The ir drop between the two points on the heating filament, owing to r remaining practically constant in value over the temperature range used, is directly proportional to the heating-current i. This, of course, is true only when such materials as Advance, Therlo or Manganin are used;-materials having a temperature coefficient of practically zero.

It should be understood that the distance between the two welds or junctions on the heating wire, in any particular case, depend upon the properties of the materials used and the application of the instrument. In order to avoid the use of excessively large values

of the heating-current and accidentally burning it out; it is necessary to obtain the "zero velocity" balance at the lowest possible value of heating-current which may be accurately measured. The value of this zero velocity current, therefore, depends to a great extent upon the sensitivity of the current measuring instrument employed. A value which has been found convenient by the author in one type of instrument was 50 milliamperes or .05 of an ampere.

In the type of Fluid-Meter developed by the author and shown in figure D, two heating elements are placed in parallel, each of which has attached at its mid-point a wire of different material so that two similar thermocouples are placed in series. One heating element is of No. 36 B. & S. Gauge Advance while the other is of Manganin or Therlo of the same gauge. At the center of the Advance wire there is welded a Manganin or Therlo wire, while at the mid-point of the Manganin or Therlo heating wire there is welded an Advance wire.

The principle of operation is as follows: Since Advance and Manganin have practically the same

VARIOUS FORMS OF THE THERMOELECTRIC FLUID-METER

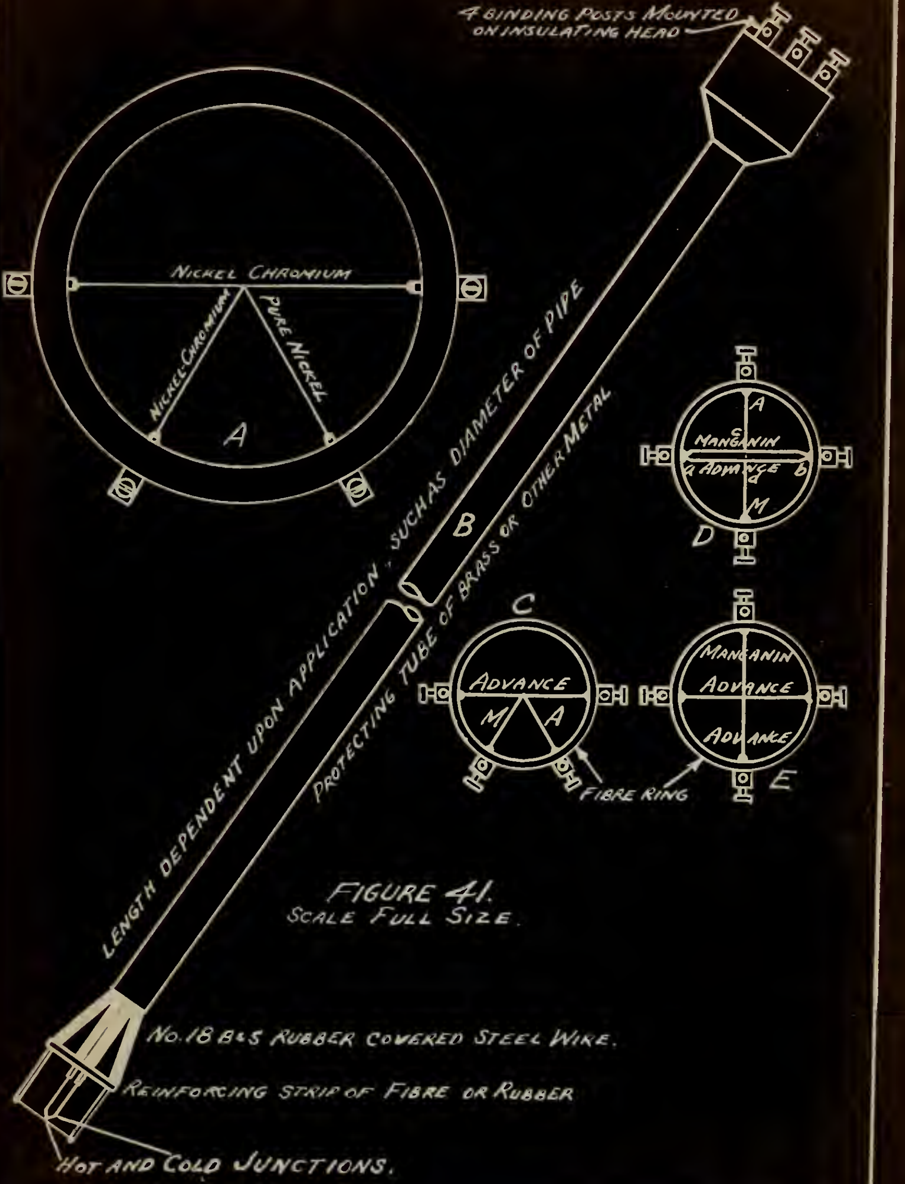
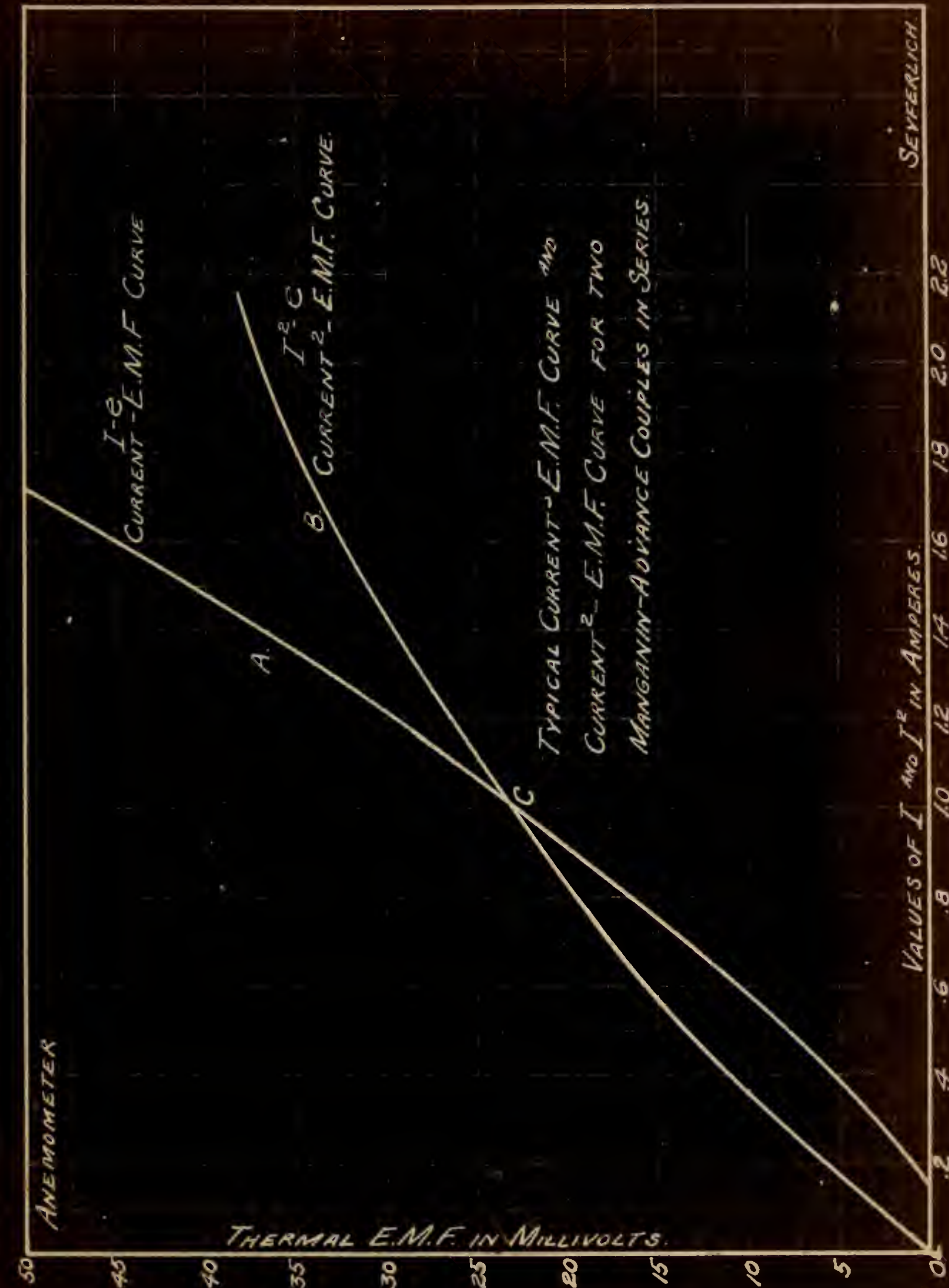

4 BINDING POSTS MOUNTED ON INSULATING HEAD
NICKEL CHROMIUM
NICKEL-CHROMIUM
PURE NICKEL
A
LENGTH DEPENDENT UPON APPLICATION, SUCH AS DIAMETER OF PIPE
B
PROTECTING TUBE OF BRASS OR OTHER METAL
A
MANGANIN
c
a ADVANCE b
d
M
D
C
ADVANCE
M
A
MANGANIN
ADVANCE
ADVANCE
E
FIBRE RING
No. 18 B&S RUBBER COVERED STEEL WIRE.
REINFORCING STRIP OF FIBRE OR RUBBER
HOT AND COLD JUNCTIONS.

FIGURE 41.
SCALE FULL SIZE.

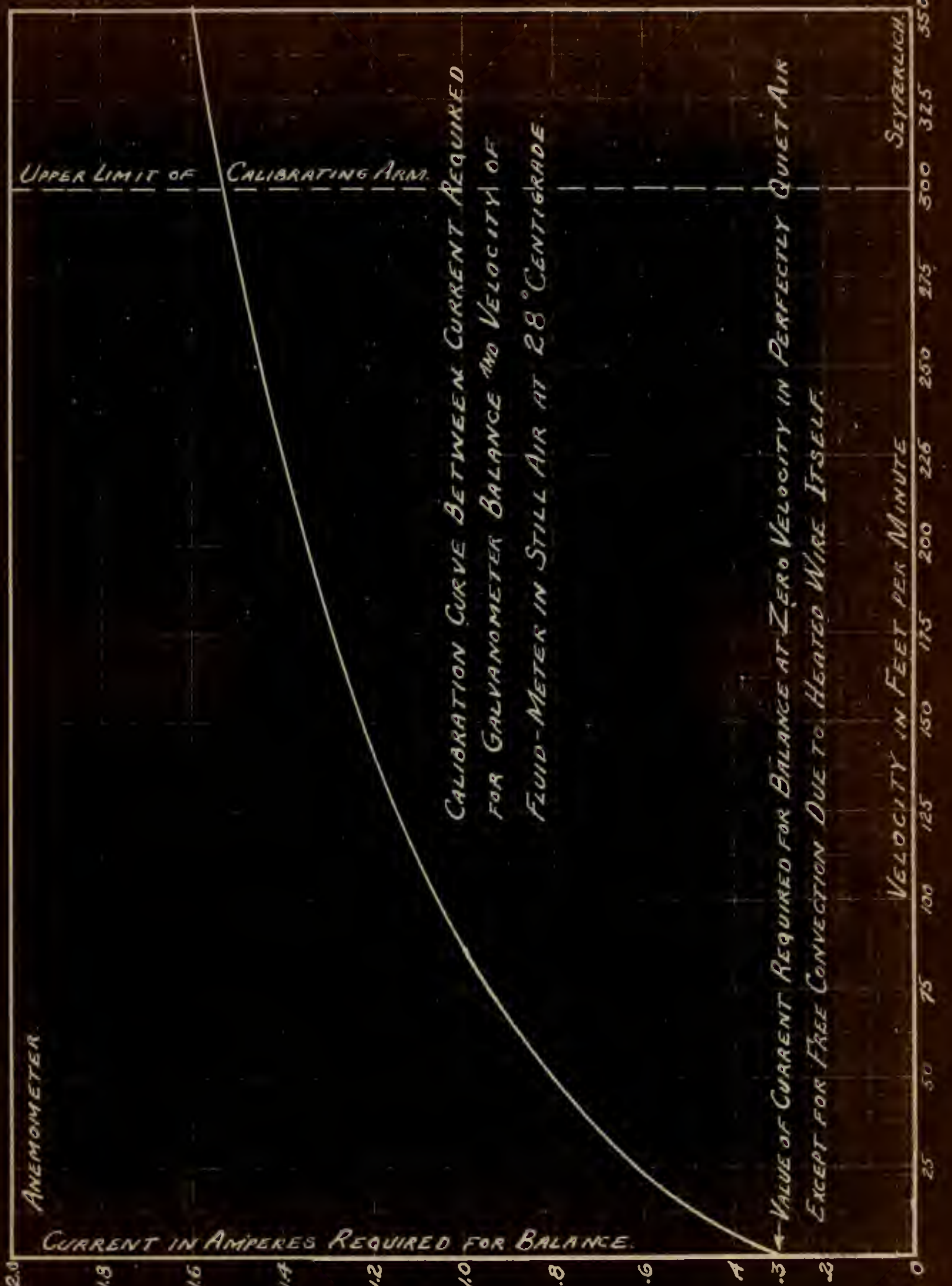


TYPICAL CURRENT-E.M.F. CURVE AND CURRENT²-E.M.F. CURVE FOR TWO MANGANIN-ADVANCE COUPLES IN SERIES.

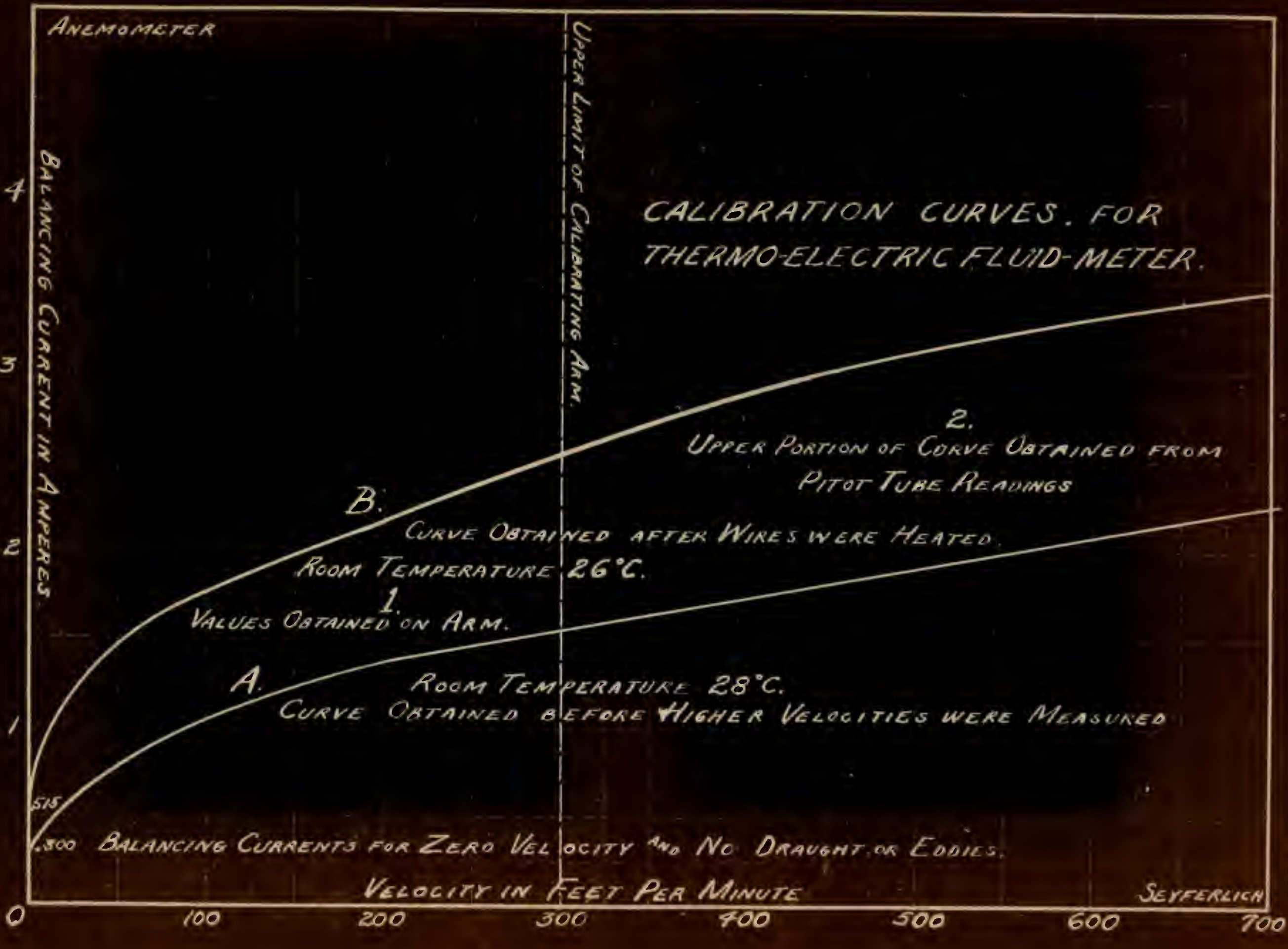
specific resistance, two such wires of the same length and gauge when placed in parallel, as indicated in figures D and 40 , will divide the current equally. Since two similar thermocouples are formed at the points c and d , the conditions at these two points will be exactly the same. In other words the temperature rise at these two points due to the heating-current will be exactly the same. With equal temperature rises at the two hot junctions, the E. M. F. developed by each couple will likewise be the same. Now if the two points be placed as close to each other as is practicable, the variations that occur at these two points, when the instrument is subjected to a moving stream of air, will be practically the same.

Although the previously described instrument possesses the great advantage of measuring the velocity more nearly at a point, the latter type possesses many distinct advantages over the former, and therefore the greater part of the time was given to the development of this particular type.

The most important features which stamp this

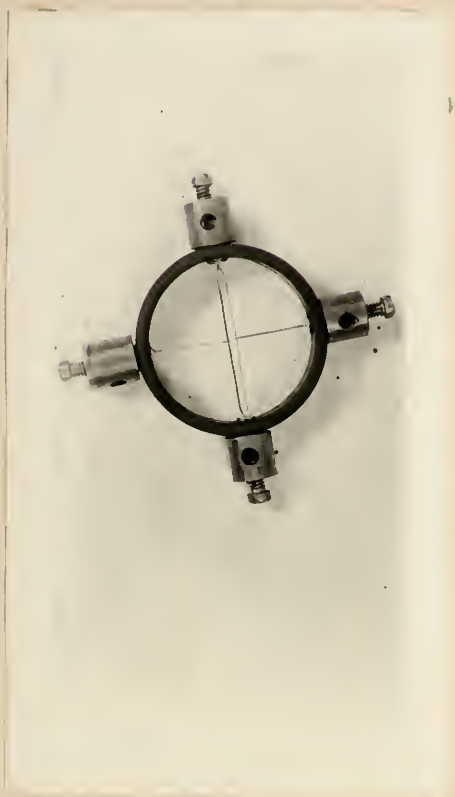


CALIBRATION CURVE BETWEEN CURRENT REQUIRED FOR GALVANOMETER BALANCE AND VELOCITY OF FLUID-METER IN STILL AIR AT 28°CENTIGRADE



CALIBRATION CURVES. FOR THERMO-ELECTRIC FLUID-METER.

FIGURE D



THE THERMOELECTRIC FLUID-METER.

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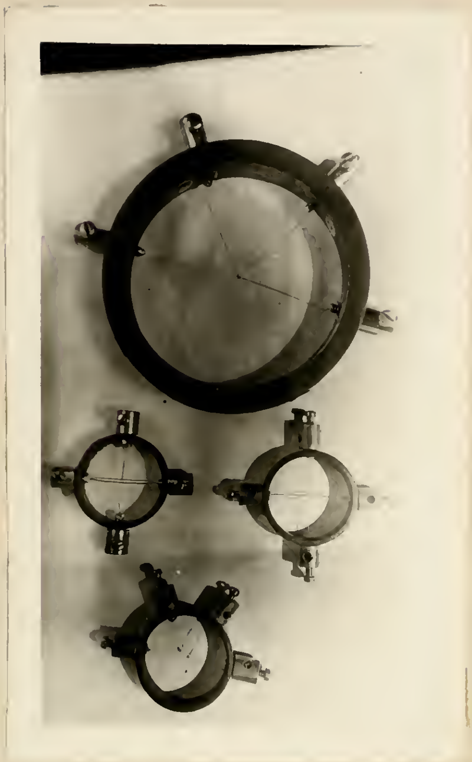
FIGURE E



VARIOUS FORMS OF THERMOELECTRIC FLUID-METER.

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instrument as a superior type may be listed as follows:

1st. It facilitates the welding of the wires used in the construction of the instrument.

2nd. The weld produced in this type is much stronger and is more reproducible.

3rd. The instrument itself when completed may be made more durable and robust.

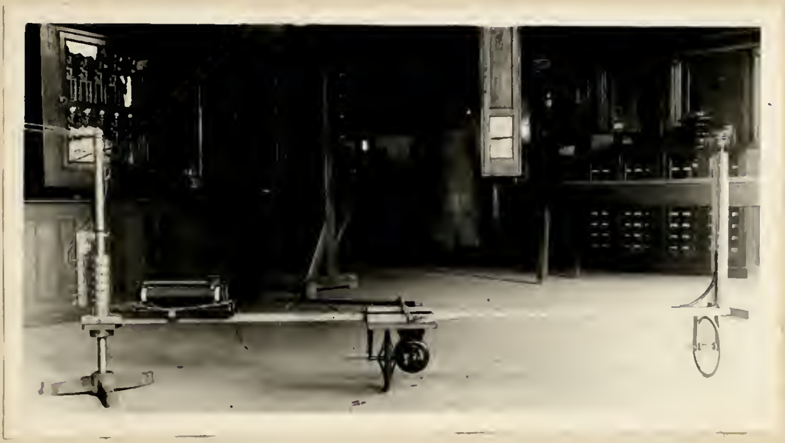
4th. The ease with which the resistance of the balancing IR drop may be controlled is also an important feature.

5th. The current-carrying capacity of the instrument is about twice that of the above mentioned type.

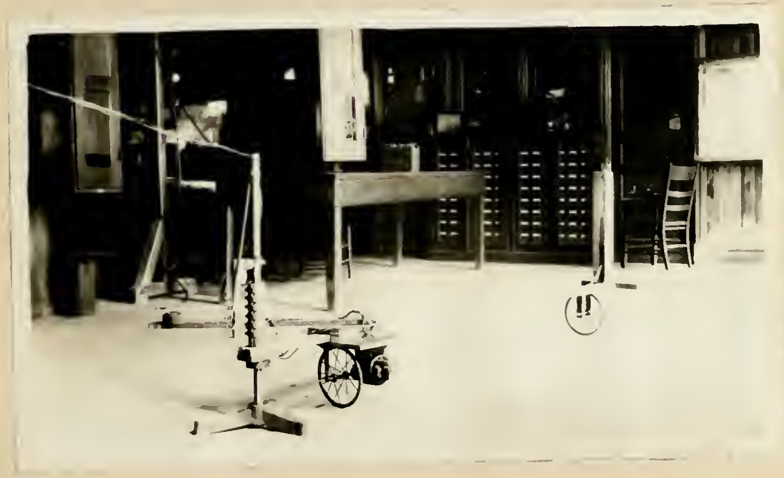
6th. Since there are two exactly similar thermocouples in series a greater deflection is produced for a given value of current through the heating elements.

7th. Owing to characteristics 5 and 6, the range of velocities covered by this type of instrument is necessarily broader and the measurements are more conveniently made.

FIGURES F and G.



THE ANEMOMETER CALIBRATING ARM.



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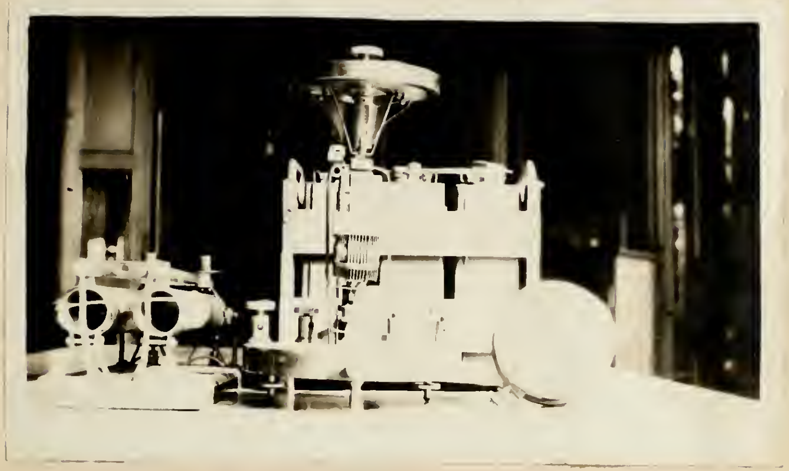
For curve A, the values of heating-current required to obtain balances for velocities ranging from zero to about 300 feet per minute, were obtained on the calibrating arm. The values found were as follows:

VELOCITY IN FEET PER MINUTE	AMPERES HEATING CURRENT
25.00	.580
37.50	.720
60.00	.810
61.20	.850
66.66	.875
75.00	.950
85.80	1.000
93.60	1.030
100.00	1.060
107.14	1.065
115.38	1.145
120.00	1.160
135.20	1.180
150.00	1.200
158.00	1.220
176.00	1.250
187.50	1.290
200.00	1.310
214.00	1.375
250.00	1.460
272.72	1.480
300.00	1.600

ROOM TEMPERATURE 28° CENTIGRADE.

The meter was next used in making a traverse across a section in a blower system, and the readings indicated were plotted against the values of velocity

FIGURES H and I.



ELECTRO-DYNAMOMETER USED FOR DIRECT MEASUREMENT OF VELOCITY.

APPARATUS FOR CALIBRATING FLUID-METER AT VARIOUS TEMPERATURES.

calculated from the readings obtained by the Pitot tube in a similar traverse but at a different point in the line. The values obtained for the balancing current required at velocities of 350, 450 and 650 feet per minute are shown in the upper part of curve B. Owing to the fact that a heating-current in excess of three amperes was allowed to pass through the heated wires when there was no air blowing past the wires, it was concluded that a change in resistance took place due to the melting of some of the solder about one or more of the junctions.

It was then realized that it would be necessary to re-calibrate the instrument on the calibrating arm, in order to see whether or not the instrument would function properly. The instrument was then remounted on the calibrating arm and, as indicated in the lower section of curve B, a new series of points were obtained.

The current and velocity values obtained in the Pitot tube test were as follows:

I	V
2.68	350
3.03	454
3.36	657

In re-calibrating the instrument after considerable usage and rough handling, the following values of current were required through the heating filaments in order to obtain galvanometer balances at the following velocities:

VELOCITY IN FEET PER MINUTE	AMPERES CURRENT REQUIRED
0	.515
25	1.250
60	1.490
64	1.520
85.80	1.650
100.00	1.750
150.00	1.850
180.00	2.000
200.00	2.150
300.00	2.480

ROOM TEMPERATURE 28° CENTIGRADE.

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METHOD OF READING VELOCITIES DIRECTLY.

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In order to read values of velocity directly, it becomes necessary to determine just what relation exists between the value of the velocity and heating-current for any given arrangement of wires subjected to air currents under any given set of conditions.

For a given thermoelectric arrangement of materials having a straight line temperature E. M. F. curve, the developed thermal e. m. f. is a function of temperature only, and for ordinary temperatures at atmospheric pressure, may be expressed as

$$e = K_1 T \qquad (1)$$

where T represents the temperature-difference between hot and cold junctions and K_1 is a constant.

But the temperature T may also be expressed in terms of the resistance of the heated wire and the heating-current, as

$$T = K_2 \, I^2 \, R \qquad (2)$$

If the wire is placed in a current of air as given above, the velocity of which is v, the relation

then becomes

$$T = \frac{K_2 I^2 R}{(v)^{\frac{1}{2}}} \qquad (3)$$

Substituting this value of T into equation

$$(1) \quad e = K_1 \times \frac{K_2 I^2 R}{(v)^{\frac{1}{2}}} \qquad (4)$$

as explained previously, for the condition of balance in the galvanometer circuit, we know that the electromotive force developed by the couple must be equal and opposite in direction to the small IR drop, or

$$e = I R \qquad (5)$$

substituting this value of e into equation (4) we obtain

$$IR = \frac{K_1 K_2 I^2 R}{(v)^{\frac{1}{2}}} \qquad (6)$$

Transposing and dividing through by IR, we obtain

$$(v)^{\frac{1}{2}} = K_1 K_2 I \qquad (7)$$

or by squaring $v = K_1^2 K_2^2 I^2$ (8)

in which, neglecting the constants K_1 and K_2 for the moment it is indicated that the velocity v is directly proportional to the square of the heating-current, or the heating-current is directly proportional to the square root of the velocity.

For direct readings of velocity, or in other words an instrument whose scale could be calibrated

directly in velocities, a meter measuring values of current squared would be required.

For such measurements, therefore, an electrody manometer might be used as indicated in figure H. In this instrument no iron or magnetic meterial is used, but the action of two coils carrying the current under measurement serves as a means of measuring the value of the current by indicating values of current squared.

In the secondary type of instrument produced by Siemens, an oblong coil is fixed in a vertical position, and surrounding it closely at right angles, but not touching it, is a rectangular suspended coil. The current under measurement passes through the fixed coil and is led into the suspended coil through two mercury cups into which itsends dip. The magnetic action of the two coils upon each other causes the suspended coil to turn, but its top end is attached to a helical spring, the upper end of which is fastened to a knob, which is turned till the torsion of the spring forces the suspended coil back again into its zero position. The strength of the current is determined

from the amount of torsion required, as indicated on a circular scale graduated in degrees of angular deflection.

In such an instrument the force of torsion t is directly proportional to the angle of torsion θ, and depends on the current strength in each coil, or in other words t is proportional to $I_F\ I_S$, but when the current is the same in each coil, t is proportional to I^2, so that

$$I = K \quad t \qquad (9)$$

or

$$I = K \quad \theta\theta \qquad (10)$$

where K is a constant for the instrument which depends upon the size, shape, and number of turns in the coils, and also the spring and scale by which the torsion is measured. The value of K may be determined for any given instrument by measuring the torsion produced by a known value of current.

When the current is reversed in both coils the deflection is in the same direction as before, so that this instrument may be employed also for measuring rapidly alternating currents, which give no deflection in a galvanometer.

It is probable, however, that it would be more convenient from a practical standpoint, to utilize such a relation existing between the value of the velocity and the power or I^2 R loss in the heated wire for direct readings of velocity. In this case a wattmeter would serve the purpose, and the scale of the wattmeter would be calibrated directly in velocities, since the power supplied the heated-wire is a direct function of the velocity.

The direct reading and indirect reading-resistance type as used by Kennelly is shown in figures 35 and 36.

METHOD OF CALIBRATION:

As in the case of other anemometers it is necessary first of all to calibrate the instrument as nearly absolute as possible. In order to do this it was necessary to construct an anemometer calibrating arm, as shown in figures F and G. The whirling arm itself was made of one inch by three inch pine, and was rotated about a vertical axis. The distance from the center of the stationary shaft to the outer

extremity of the arm was originally 15.91 feet, so that the circumference of the circle of "whirl" was exactly 100 feet. This value, of course, was most convenient in the computations and experimental tests and greatly contributed toward simplifying the calibration. The outer end of the whirling arm rested on a horizontal piece of angle-iron, to which a pair of 10" rubber-tired wheels were fastened by means of cast-iron forks. A third 10" rubber-tired wheel of exactly the same type was driven by means of a D. C. motor of 1/10th H. P. capacity, and was geared by worm gearing in a ratio of 100 to 1. The motor speed under normal running conditions was 1800 R.P.M., but in order to broaden the range of speed control or variation, a rheostat was placed in series with the armature circuit. The motor, driving-shaft,driving-wheel, etc., were mounted on a platform that could be shifted along the whirling arm, so that by varying the length of the arm it was possible to vary the speed from zero to about 750 feet per minute. The anemometer, of course, was mounted at all times on the vertical strut shown at the outer end of the whirling arm.

The strut used was a piece of a Standard De Haviland landing strut so that there was little or no disturbance of the air due to the motion of the strut. It was also proposed to measure velocity distribution about the strut in motion in order to see if the results obtained were in close agreement with those obtained about the same strut when placed in a wind tunnel. This particular investigation was not carried out, but it is the hope that results of such a test will be available for the advanced thesis.

Owing to the inconvenience of running tests in the Gymnasium and the great errors introduced by draughts and uneven flooring, the tests on the larger calibrating arm had to be abandoned.

The length of the arm was then reduced to 8 feet, as indicated in the photographs, so that the range of velocities was accordingly reduced to from zero up to 350 feet per minute. For values of velocity above this point the instrument was inserted in a pipe line of a blower system and calibrated against a well known Pitot tube. The results of such a test are indicated by curves A and B.

EFFECT OF TEMPERATURE.

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In order to determine the effect of temperature on the indications of the instrument, the meter was placed at the center and near one end of a 12" pipe about 4½ feet in length, and a series of readings were obtained when air at various temperatures flowed past the meter.

The air-flow itself was produced by an 8" electric fan placed at the opposite end of the pipe. The speed of the fan could be varied or regulated to three distinct values, the exact values of which were unknown, but for convenience were termed Low, Medium and High. Immediately back of the electric fan there was placed three electric heaters, so that the temperature of the air drawn by the fan could be varied practically at will. As shown in figure I a thermometer was inserted at the center of the pipe and temperature readings were recorded for each reading of the Fluid-Meter. The room temperature was also recorded for each series of readings.

The results obtained, as indicated in tabular

form below, do not afford sufficient data for forming any definite conclusions as to exactly how the temperature enters. As a first approximation, however, it seems to be indicated that the higher the temperature of the air flowing past the meter, the higher will be the value of current required to raise the temperature of the heated wire a given amount above the air temperature.

With the meter exactly at the center of the pipe the following results were obtained for the values of current required for a galvanometer balance:

ROOM TEMPERATURE 30° C.	VALUES OF CURRENT.		
	L	M	H
Air Temperature 32.5° C.	2.18	2.38	2.58
Air Temperature 36° C.	2.26	2.44	2.60

In such a test, it should be understood, that the quantity of air delivered by the fan is approximately proportional to the speed and not necessarily the velocity. For this reason it was deemed appropriate to make a check on the above results by traversing the sectional area of the pipe at the point

in question.

Readings of the meter at intervals of one inch across a horizontal diameter produced the following results:

VALUES OF HEATING CURRENT

Temperatures ° C.	29	29	29	33	34½	35½
Fan Speeds	L	M	H	L	M	H
	1.44	2.32	2.68	2.27	2.57	2.71
	2.27	2.48	2.80	2.37	2.57	2.77
	2.25	2.47	2.67	2.37	2.56	2.72
	2.18	2.45	2.67	2.35	2.47	2.68
	2.12	2.38	2.65	2.28	2.47	2.65
	2.10	2.32	2.63	2.23	2.47	2.63
	2.12	2.34	2.63	2.23	2.40	2.61
	2.24	2.38	2.63	2.23	2.38	2.65
	2.28	2.45	2.72	2.32	2.37	2.67
	2.36	2.57	2.88	2.32	2.53	2.67

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CONCLUSIONS.

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In concluding, it is the wish of the author to express his sincere thanks to Professor Freeman and Mr. Davies for their continued interest and timely suggestions which aided materially in obtaining favorable results.

It is also desirable to express appreciation for the co-operation of Messrs. Christoffersen and Thorpe, whose practical suggestions greatly assisted in the solution of the many problems connected with the work.

The author feels likewise indebted to Messrs. Agle, Kennedy, Petersen, Falk and Rucker for suggestions given and courtesies shown.

Signed Walter M. Seyferlich

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